THE APPLICATION 2D ELECTRICAL RESISTIVITY IN IDENTIFYING SLOPE FAILURE AT SPECIFIC LOCATION IN UTP

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CIVIL ENGINEERING
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FINAL YEAR RESEARCH PROJECT REPORT

Submitted to the Civil Engineering Programme
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for the Degree
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(Civil Engineering)

Universiti Teknologi Petronas
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohammad Azrul Bin Musa

ABSTRACT

Slope failure are among common problem occur around the world. Several techniques have been use to detect the slope failure. Most of the slope failure happened because the presence of water. Geotechnical investigation is the most common technique that can detect the reason of slope failure. In this study, 2-D resistivity imaging technique had been used to map the geological structure in vertical cross section. 2-D resistivity imaging technique was used to detect the presence of water within the slope. A number of survey lines were carried out at two locations to study about this matter. One site located at slope behind building 13 at Universiti Teknologi Petronas. At this site, this 2-D imaging technique was used to detect the effect of moisture content to resistivity and the effect of wet and dry condition to slope resistivity data. Next site is located near site 1 but 2-D imaging technique has been used to detect the geology properties of this site. The result in this study shows that the 2-D resistivity imaging technique can successfully map the effect of water in soil. However, this result can successfully detected were depend on the electrode configuration, electrode spacing and cable length. Clear image of water effect is also depending on the sensitivity of the instruments used as well on the surrounding geology of the study area.

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CHAPTER 1

1.0 INTRODUCTION

A landslide (or landslip) (Figure 1) is a geological phenomenon which includes a wide range of ground movement, such as rock falls, deep failure of slopes and shallow debris flows, which can occur in offshore, coastal and onshore environments the action of gravity is the primary driving force for a landslide to occur, there are other contributing factors affecting the original slope stability. Typically, pre-conditional factors build up specific sub-surface conditions that make the area/slope prone to failure, whereas the actual landslide often requires a trigger before being released.

Figure 1: Landslide in UTP

Landslides are caused when the stability of a slope changes from a stable to an unstable condition. A change in the stability of a slope can be caused by a number of factors, acting together or alone. Natural causes of landslides include:

- groundwater (porewater) pressure acting to destabilize the slope
- Loss or absence of vertical vegetative structure, soil nutrients, and soil structure (e.g. after a wildfire)
- erosion of the toe of a slope by rivers or ocean waves
- weakening of a slope through saturation by snowmelt, glaciers melting, or heavy rains
- earthquakes adding loads to barely-stable slopes
- earthquake-caused liquefaction destabilizing slopes
- volcanic eruptions

Lanslides are aggravated by human activities, Human causes include: deforestation, cultivation and construction, which destabilize the already fragile slopes

- vibrations from machinery or traffic
- blasting
- earthwork which alters the shape of a slope, or which imposes new loads on an existing slope
- Construction, agricultural or forestry activities (logging) which change the amount of water which infiltrates the soil.

In most cases landslides occurs in the unstable soil slope. Soil is made up in part of finely ground rock particles, grouped according to size as sand, silt and clay. Each size plays a significantly different role. For example, the largest particles, sand, determine aeration and drainage characteristics, while the tiniest, sub-microscopic clay particles, and are chemically active, binding with water and plant nutrients. The ratio of these sizes determines soil type: clay, loam, clay-loam, silt-loam, and so on. In addition to the mineral composition of soil, humus (organic material) also plays a crucial role in soil characteristics and fertility for plant life. Soil may be mixed with larger aggregate, such as pebbles or gravel. Not all types of soil are permeable, such as pure clay.

There are many recognized soil classifications, both international and national. The soil identification can be done by using different type of research. The example study that can be use is electrical resistivity, wire line logging, and bore logging. These surveying need certain equipment that can do the soil identification. Electrical resistivity needs to use ABEM Terrameter SAS 4000 and ES 464.

1.1 Background Study.

This project mainly about the application of 2D electrical resistivity in identifying slope failure in UTP as shown in Figure 1. The slope failure occur because the effect of water in the soil at the slope. This can be measure by the moisture content in the soil from borehole data. There is field experiment conducted to study the effect of different saturation for wet and dry condition. Based on the research conducted the slope failure can be identify due to certain factor. Soil becomes weak because the present of water that change the properties of soil. This study also involves the bore log investigation to compare with electrical resistivity data in determine the potential weak zone of slope failure.

1.2 Problem Statement

In UTP there are many potential area of slope failure. Several million ringgit has been spent to stabelised the slope, however a few of them fail. Geologically this are is made of interbeded sandstone and shale. The weathering profile of this rock give considerably thic sequence of fine grain clayey sand soil. The condition in UTP also changes from dry to wet because of the weather effect. This also gives impact to moisture content of soil. Slope failure occurs due to certain factor. Most of them because the effect of water in the soil.

1.3 Objective of the study

- To investigate the difference of the electrical resistivity due to change in dry and wet condition.
- To determine the relation between moisture content in soil with resistivity data.
- To determine the relation between SPT value with resistivity data.

1.4 Scope of study

The study of comparison between electrical resistivity with wire line log and bore log data in soil is to be completed within the time frame given which is approximately 2 semesters. So by doing this comparison, the relation between moisture content in soil, SPT value and resistivity data can be determined. The study for the first semester is based on comparison between electrical resistivity with wire line log and bore log. For the second semester, more focusing in different effect of wet and dry condition at site using electrical resistivity equipment. This study needed to know the effect of that condition to the soil.

The location for this study is the slope behind Building 13 at Universiti Teknologi Petronas, Perak. To accomplish the study, research, allocating the resource, work planning is to be done within this time frame. This study is more on to see the comparison between the electrical resistivity with geotechnical investigation data due to the factor that leads slope failure in UTP area. This study also involving the RES2DINV ver. 3.57 Geotechnical Imaging 2D and 3D Geotomo software. This is for plotting the resistivity value.

For wire line logging and bore logging has been done by the contractor. By using the data from that field experiment the author done some comparison to determine the effect of water to slope failure.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Electrical resistivity

The electrical resistivity methods allow a current to circulate through the ground between a pair of electrodes (A and B), and the potential difference is measured with another pair of electrodes (M and N), providing a measure of the electrical resistance of the soil system. The depth of penetration increases with the distance between the AB electrodes. When the soil is not electrically homogeneous, the current lines and equipotential surfaces are distorted. In order to detect the crack presence, position, and extension, electrical resistivity measurement were done by a 2D vertical pseudo-section (Loke, Baker, 1996).

The resistivity of soil depends on various components that form the sediments: carbonates, organic matter, mineral noncarbonated components, and pore water. In the research, especially pore water mineralization was taken into consideration, because the resistance of soil is first of all a function of the electrolyte contained in the pore spaces (Attewel, Farmer, 1976). This various components will give effect to the resistance when doing the research.

An electrical resistivity measurement normally was carried out using an ABEM SAS 4000 Terrameter. An electrode selector ES 464 is connected to steel electrodes in a straight line with constant spacing via ABEM Lund multi core cables. A Wenner electrode configuration was used and the 2D resistivity data were recorded by the Terrameter. The measured data were processed by a 2D inverse modeling program using Loke and Barker (1996) inversion methods to produce a 2D resistivity inversion image. This image will give some pattern of that soil. From that image also we can determine the crack, hole, and the type of that soil.

2.1.1 Theory

In a homogeneous earth, current flows radially outward from the source to dfine a hemispherical surface. The current distribution is equal everywhere on this surface which is also called an equipotential surface. Starting with Ohm's law ($V = IR$) and defining the resistance R in terms of the resistivity _ and the area of the shell (equipotential surface), the potential difference across the shell is

$$dV = i(R) = I\left(\rho \frac{L}{A}\right) = I\left(\rho \frac{dr}{2\pi r^2}\right)$$

where V is the voltage (or electrical potential), I is the current, _ is the resistivity, and r is the radius of the equipotential surface. Integrating the above equation and setting the potential at infinity to zero, the electric potential at a distance R from the source is given by

$$V = \frac{\rho I}{2\pi R}$$

Resistivity has units of *ohm m* and is not to be confused with *resistance* which has units of *ohms*. The *resistivity* of a material is defined as $\rho = RA/L$ where R is the resistance of the material, A is the cross-sectional area through which current flows and L is the length on the material.

The potential has been derived due to a single current source. The goal in resistivity surveying is to measure the potential different between two points due to the current from two current electrodes. The potential at each electrode is determined due to the current sources:

$$V_{P1} = \frac{I\rho}{2\pi r_1} - \frac{I\rho}{2\pi r_2}$$

$$V_{P2} = \frac{I\rho}{2\pi r_3} - \frac{I\rho}{2\pi r_4}$$

The potential difference $V = VP1 - VP2$ which simplifies to

$$\Delta V = \frac{I\rho}{2\pi}\left(\frac{1}{r_1} - \frac{1}{r_2} - \frac{1}{r_3} + \frac{1}{r_4}\right)$$

The above equation can then be solved for the resistivity. In a no homogeneous earth, the resistivity which is measured is not actually the true resistivity of the subsurface. For an earth with more than one layer, the *apparent resistivity* measured will be an average of the resistivity of the additional layers. The apparent resistivity data needs to be interpreted in terms of a subsurface model in order to determine the actual resistivity of the layers.

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameters such as the mineral and fluid content, porosity and degree of water saturation in the rock. The resistivity measurements are normally made by injecting current into the ground through two current electrodes (C1 and C2), and measuring the resulting voltage difference at two potential electrodes (P1 and P2). From the current (I) and voltage (V) values, an apparent resistivity (*pa*) value is calculated.

$$pa = \mathrm{k}\ \mathrm{V} / \mathrm{I}$$

where k is the geometric factor which depends on the arrangement of the four electrodes. Figure 2 shows the common arrays used in resistivity surveys together with their geometric factors. Resistivity meters normally give a resistance value, R = V/I, so in practice the apparent resistivity value is calculated by

$$pa = \mathrm{k}\ \mathrm{R}$$

The calculated resistivity value is not the true resistivity of the subsurface, but an "apparent" value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between the "apparent" resistivity and the "true" resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out.

2.1.2 Survey methods and electrode configurations

Resistivity surveys are conducted as either soundings or profiles. A sounding is used to determine changes in resistivity with depth. The electrode spacing is varied for each measurement, but the center point of the array is constant. A resistivity profile is used to detect lateral variations in resistivity. For this configuration, the electrode spacing is fixed while the center of the array is varied. There are various electrode configurations which can be used in resistivity surveying. The apparent resistivity measured by the array depends on the geometry of the electrodes. The majority of resistivity surveys use two current electrodes and two potential electrodes.

The two main array configurations are the Wenner array and the Schlumberger array. The Wenner array has the simplest geometry, with all of the electrodes equally spaced. This is illustrated in figure 2. The Schlumberger array is more complex with the spacing between the current electrodes not equal to the spacing between the potential electrodes. The Schlumberger array is shown in figure 2. In general, the potential electrode spacing is negligible compared to the current electrode spacing for this type of array.

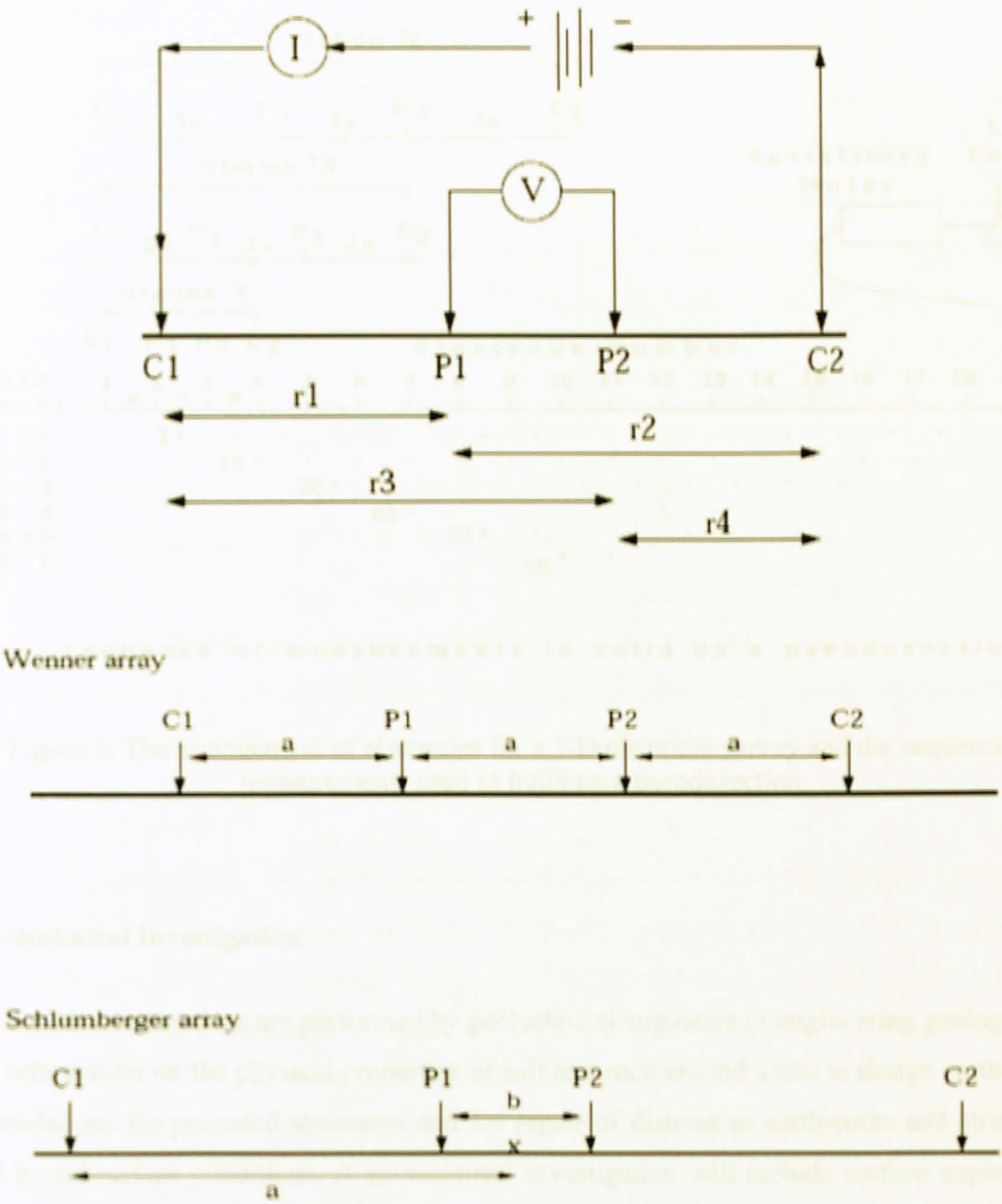


Figure 2: the common array

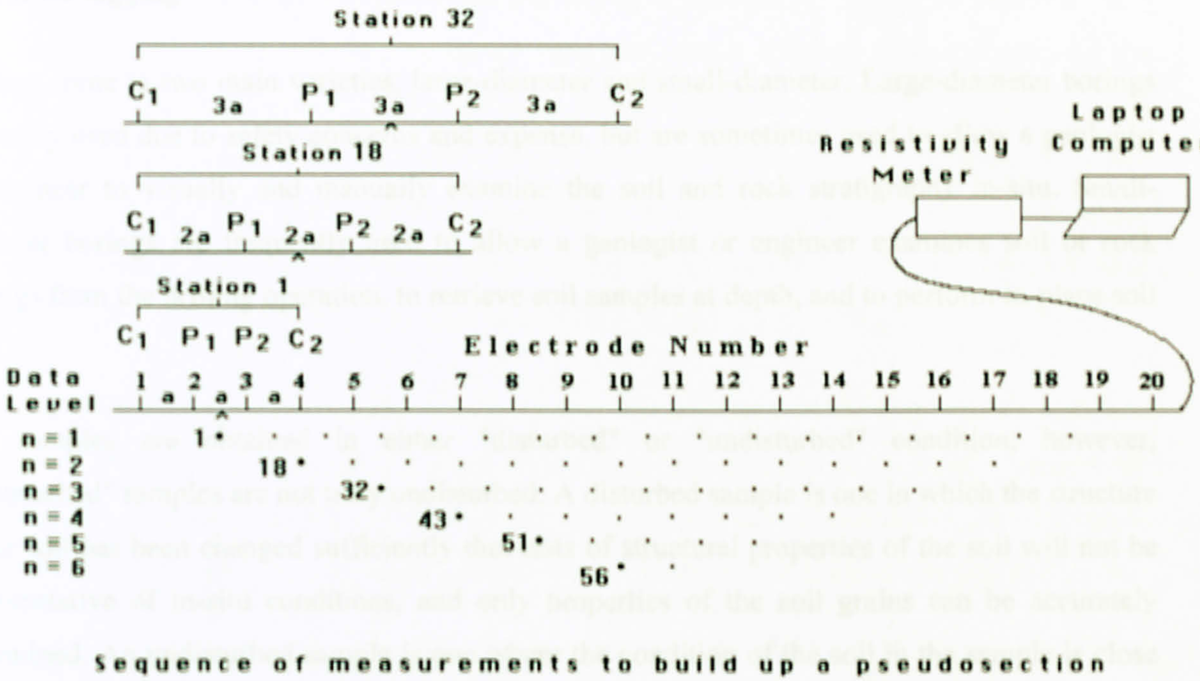


Figure 3: The arrangement of electrodes for a 2-D electrical survey and the sequence of measurements used to build up a pseudosection.

2.2 Geotechnical Investigation

Geotechnical investigations are performed by geotechnical engineers or engineering geologists to obtain information on the physical properties of soil and rock around a site to design earthworks and foundations for proposed structures and for repair of distress to earthworks and structures caused by subsurface conditions. A geotechnical investigation will include surface exploration and subsurface exploration of a site. Sometimes, geophysical methods are used to obtain data about sites. Subsurface exploration usually involves soil sampling and laboratory tests of the soil samples retrieved. Surface exploration can include geologic mapping, geophysical methods, and photogrammetric. To obtain information about the soil conditions below the surface, some form of subsurface exploration is required. Methods of observing the soils below the surface, obtaining samples, and determining physical properties of the soils and rocks include test pits, trenching (particularly for locating faults and slide planes), boring, and in situ tests.

2.2.1 Bore logging

Borings come in two main varieties, large-diameter and small-diameter. Large-diameter borings are rarely used due to safety concerns and expense, but are sometimes used to allow a geologist or engineer to visually and manually examine the soil and rock stratigraphy in-situ. Small-diameter borings are frequently used to allow a geologist or engineer examines soil or rock cuttings from the drilling operation, to retrieve soil samples at depth, and to perform in-place soil tests.

Soil samples are obtained in either "disturbed" or "undisturbed" condition; however, "undisturbed" samples are not truly undisturbed. A disturbed sample is one in which the structure of the soil has been changed sufficiently that tests of structural properties of the soil will not be representative of in-situ conditions, and only properties of the soil grains can be accurately determined. An undisturbed sample is one where the condition of the soil in the sample is close enough to the conditions of the soil in-situ to allow tests of structural properties of the soil to be used to approximate the properties of the soil in-situ. Borehole logging is the practice of making a detailed record (a *well log*) of the geologic formations penetrated by a borehole.

The log may be based either on visual inspection of samples brought to the surface (*geological* logs) or on physical measurements made by instruments lowered into the hole (*geophysical* logs). Well logging is done when drilling boreholes for oil and gas, groundwater, minerals, and for environmental and geotechnical studies.

2.2.2 Wire line logging

A continuous measurement of formation properties with electrically powered instruments to infer properties and make decisions about drilling and production operations. The record of the measurements, typically a long strip of paper, is also called a log. Measurements include electrical properties (resistivity and conductivity at various frequencies), sonic properties, active and passive nuclear measurements, dimensional measurements of the wellbore, formation fluid sampling, formation pressure measurement, wire line-conveyed sidewall coring tools, and others.

In wire line measurements, the logging tool (or probe) is lowered into the open wellbore on a multiple conductor, contra-helically armored wire line. Once lowered to the bottom of the interval of interest, the measurements are taken on the way out of the wellbore. This is done in an attempt to maintain tension on the cable (which stretches) as constant as possible for depth correlation purposes. (The exception to this practice is in certain hostile environments in which the tool electronics might not survive the temperatures on bottom for the amount of time it takes to lower the tool and then record measurements while pulling the tool up the hole.

In this case, "down log" measurements might actually be conducted on the way into the well, and repeated on the way out if possible.) Most wire line measurements are recorded continuously even though the probe is moving. Certain fluid sampling and pressure-measuring tools require that the probe be stopped, increasing the chance that the probe or the cable might become stuck.

2.2.3 Electrical resistivity using wire line log

Two types of resistivity measurement tools are available on board: the Dual Laterolog (DLL) and the DIT. The former has a response range of 0.2-40,000 Ωm and measures the direct resistivity of a formation. It is mostly applied in medium- to high-resistivity formations in igneous environments (e.g., oceanic basalts and gabbros). The DIT, with a response range of 0.2-2,000 Ωm, is a conductivity-sensitive device and is most commonly applied in low- to medium-resistivity formations such as sediments. However, it has also produced very good results in ocean-crust basalts.

The DIT has a deep induction phasor-processed device (IDPH), a medium induction phasor-processed device (IMPH), a spherically focused resistivity measurement (SFLU), and a spontaneous potential (SP) device. The two induction devices transmit high-frequency alternating currents through transmitter coils, creating time-varying magnetic fields that induce currents in the formation. These induced currents create, in turn, a magnetic field that induces new currents in the receiver coils, producing a voltage. The currents are proportional to the conductivity of the formation, as is the voltage. The SFLU is a shallow-penetration galvanic device that measures the current necessary to maintain a constant voltage drop across a fixed interval of the formation.

In high-resistivity formations (>100 Ωm), both IDPH and IMPH measurements may be erroneous, but the error can be greatly reduced by downhole calibration. In such cases, SFLU measurements produce good results, similar to the DLL device (Shipboard Scientific Party, 1998). The resistivity of a rock is controlled largely by the porosity of the rock, the properties of the pore fluid(s), and the connectivity of the pores.

Spontaneous potentials can originate from a variety of causes, electrochemical, electro thermal, and electro kinetic streaming potentials, and membrane potentials as a result of differences in the mobility of ions in the pore and drilling fluids. SP may be useful to infer fluid-flow zones and formation permeability.

2.2.4 Standard penetration test

The standard penetration test (SPT) is an in-situ dynamic penetration test designed to provide information on the geotechnical engineering properties of soil. The test procedure is described in the British Standard BS EN ISO 22476-3 and ASTM D1586.

Figure 4: SPT equipment

The main purpose of the test is to provide an indication of the relative density of granular deposits, such as sands and gravels from which it is virtually impossible to obtain undisturbed samples. The great merit of the test and the main reason for its widespread use is that it is simple and inexpensive. The soil strength parameters which can be inferred are approximate, but may give a useful guide in ground conditions where it may not be possible to obtain borehole samples of adequate quality like gravels, sands, silts, clay containing sand or gravel and weak rock.

In conditions where the quality of the undisturbed sample is suspect, e.g. very silty or very sandy clays, or hard clays, it is often advantageous to alternate the sampling with standard penetration tests to check the strength. If the samples are found to be unacceptably disturbed, it may be necessary to use a different method for measuring strength like the plate test.

When the test is carried out in granular soils below groundwater level, the soil may become loosened. In certain circumstances, it can be useful to continue driving the sampler beyond the distance specified, adding further drilling rods as necessary. Although this is not a standard penetration test, and should not be regarded as such, it may at least give an indication as to whether the deposit is really as loose as the standard test may indicate.

The usefulness of SPT results depends on the soil type, with fine-grained sands giving the most useful results, with coarser sands and silty sands giving reasonably useful results, and clays and gravelly soils yielding results which may be very poorly representative of the true soil conditions. Soils in arid areas, such as the Western United States, may exhibit natural cementation. This condition will often increase the standard penetration value.

The SPT is used to provide results for empirical determination of a sand layer's susceptibility to earthquake liquefaction, based on research performed by Harry Seed, T. Leslie Youd, and others.

2.3 Slope stability

The field of slope stability encompasses the analysis of static and dynamic stability of slopes of earth and rock-fill dams, slopes of other types of embankments, excavated slopes, and natural slopes in soil and soft rock. Slope stability investigation, analysis (including modeling), and design mitigation is typically completed by geologists, engineering geologists, or geotechnical engineers. Geologists and engineering geologists can also use their knowledge of earth process and their ability to interpret surficial geomorphology to determine relative slope stability based simply on site observations.

As seen in Figure 5 , earthen slopes can develop a cut-spherical weakness area. The probability of this happening can be calculated in advance using a simple 2-D circular analysis package. A primary difficulty with analysis is locating the most-probable slip plane for any given situation. Many landslides have only been analyzed after the fact.

Real life failures in naturally deposited mixed soils are not necessarily circular, but prior to computers, it was far easier to analyze such a simplified geometry. Nevertheless, failures in 'pure' clay can be quite close to circular. Such slips often occur after a period of heavy rain, when the pore water pressure at the slip surface increases, reducing the effective normal stress and thus diminishing the restraining friction along the slip line. This is combined with increased soil weight due to the added groundwater.

A 'shrinkage' crack (formed during prior dry weather) at the top of the slip may also fill with rain water, pushing the slip forward. At the other extreme, slab-shaped slips on hillsides can remove a layer of soil from the top of the underlying bedrock. Again, this is usually initiated by heavy rain, sometimes combined with increased loading from new buildings or removal of support at the toe (resulting from road widening or other construction work). Stability can thus be significantly improved by installing drainage paths to reduce the destabilizing forces. Once the slip has occurred, however, a weakness along the slip circle remains, which may then recur at the next monsoon.

Slope stability issues can be seen with almost any walk down a ravine in an urban setting. An example is shown in Figure, where a river is eroding the toe of a slope, and there is a swimming pool near the top of the slope. If the toe is eroded too far, or the swimming pool begins to leak, the forces driving a slope failure will exceed those resisting failure, and a landslide will develop, possibly quite suddenly.

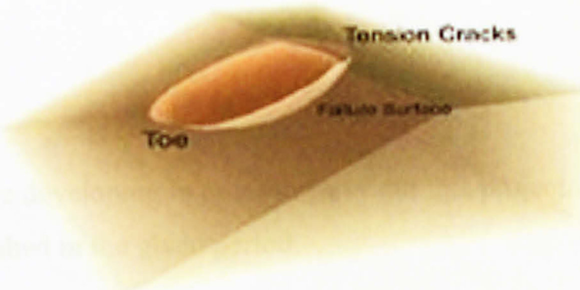


Figure 5: Simple slope slip section

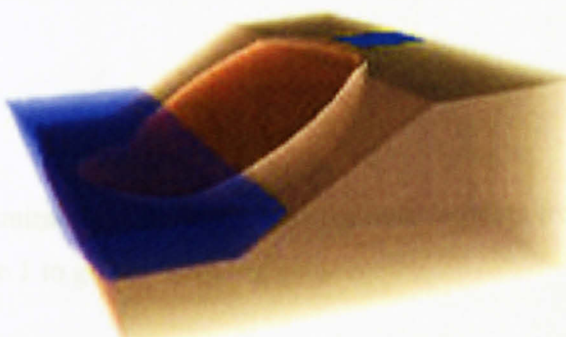


Figure 6: Slope with eroding river and swimming pool

CHAPTER 3

3.0 PROJECT FLOW

3.1 Procedure.

There are some procedure are developing in order to carry out this project. This is to ensure that the project flow is accomplished in the given period.

3.1.1 Research.

The research involve in this study scope are to find the standard method of electrical resistivity, bore log, and wire line logging. This research part also includes the literature review gathering based on the three methods which is electrical resistivity, bore log, and wire line logging. From this research the author can make preparation due to this study.

3.1.2 Site Investigation

a) Boring

Boring has been done by contractor. Contractor gets the bore log data from this boring. This boring has been done at site 1 to get the bore log data.

b) Wire line logging

Wire line logging has been done by contractor. Contractor used wire line logging method in this part to get the data. This has been done at site 2.

c) Electrical resistivity

This study aims to get the data from electrical resistivity by using the ABEM Terrameter 4000 and ABEM Electrode Selector ES464. This process has been done at site 1 and 2 near Building 13 at UTP.

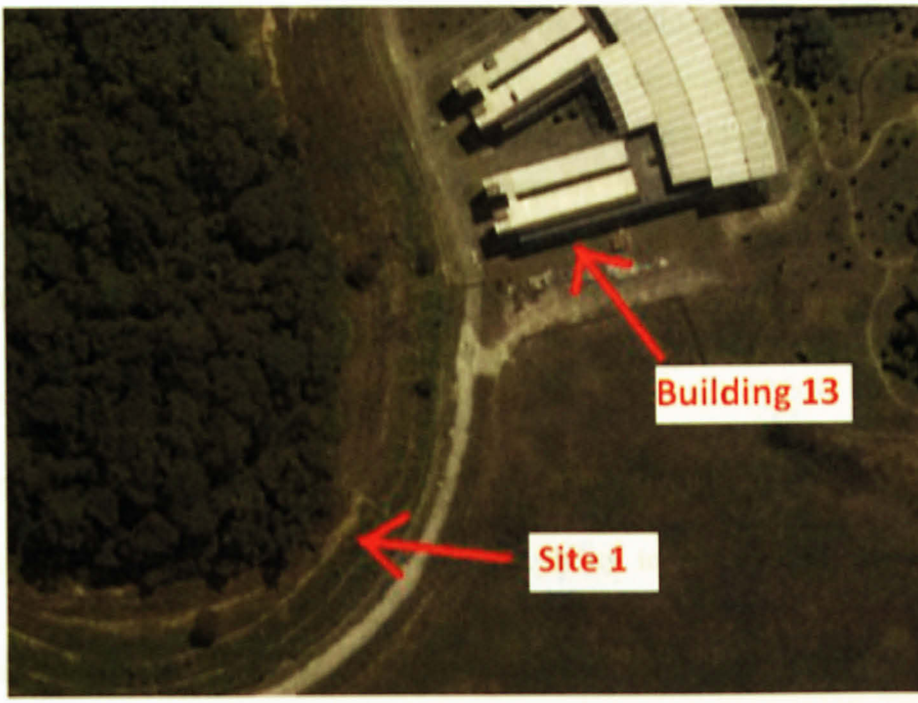


Figure 7: Location of the site 1

3.1.3 Data Gathering

All the bore hole data will first be gathered in the Log File software. Besides that, the data from resistivity has been uploading using RES2DINV ver. 3.57 Geotechnical Imaging 2D and 3D Geotomo software. Data from wire line logging and bore log has been gathered by the contractor. From the data, the comparison between electrical resistivity with bore log and wire line logging data can be relate to verify the type of soil in UTP and by using electrical resistivity also the comparison due to wet and dry condition can be done.

3.2 Tool Required.

3.2.1 RES2DINV ver. 3.57 Geotechnical Imaging 2D and 3D Geotomo software

This software is used to plot the electrical resistivity value in 2D or 3D view. Based on the result from this software, it shows the type of soil at that site. To interpret the data from a 2-D imaging survey, a 2-D model for the subsurface which consists of a large number of rectangular blocks is usually used.

A computer program is then used to determine the resistivity of the blocks so that the calculated apparent resistivity values agree with the measured values from the field survey. The computer program RES2DINV.EXE will automatically subdivide the subsurface into a number of blocks, and it then uses a least-squares inversion scheme to determine the appropriate resistivity value for each block. The location of the electrodes and apparent resistivity values must be entered into a text file which can be read by the RES2DINV program.

3.2.2 Electrical Resistivity Tools

a) ABEM Terrameter SAS4000

A useful facility of the Terrameter SAS 4000 is its ability to measure in four channels simultaneously. This implies resistivity test can be performed up to four times faster. The electrically isolated transmitter sends out well-defined and regulated signal current, with strength up to 1000 mA and voltage up to 400 V. it can be used to determine the ground resistance of grounding arrangements at power plants and along power lines and in can be use as ohmmeter.

Table 1: Terrameter SAS 4000 specification

Term	Specification
Memory capacity	More than 30 000 readings.
Serial interface	RS 232 for communication
Parallel interface	Contronics
External devices	Lund imaging system, Multimac, SASLOG 200/300
Power consumption	300 mA. Up to 15 A during transmission high current.
Weight	4.6 kg
Dimension	105 x 325 x 300 mm (W x L x H) with power pack
Number of input channels	4, galvanic isolated
Automatic ranging	+- 250 mV, +- 10 V, +- 400 V

Figure 8: ABEM Terrameter SAS4000

b) ABEM Electrode Selector ES464

Table 2: specification of electrode selector ES 464

Term	Specification
Number of channel	4 x 64 channels standard configuration. Can be linked up to four ES 464 using one serial port
Power	12 V DC clip on re-chargeable battery
Power consumption	Operates several days on a charged battery
Operating temperature	-10 o C to + 70 o C
Casing	Waterproof, rugged cast aluminium
Dimensions	W x L x H : 105 x 325 x 300mm
Weight	6.7 kg (including battery pack)
Resistivity instrument	The lund imaging system requires ABEM Terrameter SAS 4000.

Figure 9: ABEM Electrode Selector ES464

c) ABEM Lund Cable and Sealed acid battery 12V.

Figure 10: ABEM Lund Cable

Figure 11: Sealed acid battery 12V

d) Electrodes

The purpose of an electrode is to establish electric contact between electrical conductors (the cable) to an ionic conductor (the earth). All sort of electrodes generate "noise". This is of importance only at the potential electrodes. Noise is defined as the fluctuating voltage that appears between a pair of electrodes, placed so close that no other "natural" voltages appear. One way to measure the electrode noise is to place two electrodes in a case filled with soil, and registrate the fluctuating voltage as a function of time. Stainless steel is better that ordinary steel.

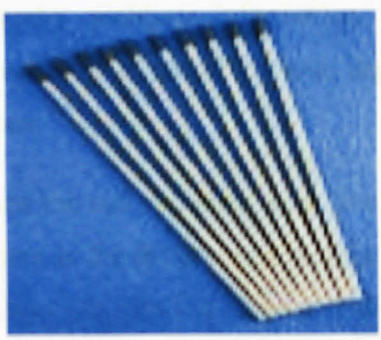


Figure 12: Electrode

CHAPTER 4

4.0 METHODOLOGY

The electrical resistivity method involves measuring the apparent resistivity of soils and rock as a function of depth or position. The resistivity of soils is a complicated function of porosity, permeability, ionic content of the pore fluids, and clay mineralization. The most common electrical methods used in hydro geologic and environmental investigations are vertical electrical soundings (resistivity soundings) and resistivity profiling.

During a resistivity survey, current is injected into the earth through a pair of current electrodes, and the potential difference is measured between a pair of potential electrodes. The current and potential electrodes are generally arranged in a linear array. Common arrays include the dipole-dipole array, pole-pole array, Schlumberger array, and the Wenner array. The apparent resistivity is the bulk average resistivity of all soils and rock influencing the current. It is calculated by dividing the measured potential difference by the input current and multiplying by a geometric factor specific to the array used and electrode spacing.

In a resistivity sounding, the distance between the current electrodes and the potential electrodes is systematically increased, thereby yielding information on subsurface resistivity from successively greater depths. The variation of resistivity with depth is modeled using forward and inverse modeling computer software.

This study more concern about how the soil becomes weak due to present of water and the effect to soil properties. The other element is the different saturation for wet and dry condition in that area. This study has been done at two site, site 1 at slope and site 2 at horizontal plane. For site 1, electrical resistivity and bore log data has been used to identify the potential weak zone of slope failure and relationship of resistivity with moisture content and SPT value. Resistivity has been conducted by the author but for bore log has been done by contractor. For site 2, experiment of electrical resistivity and wire line logging has been done. In this site author more concern about the relationship of wire line log data and resistivity in determine the geology properties of that site. The author has been divided the methodology into three parts.

4.1 Study of relationship between moisture content and electrical resistivity.

In this part, the\author used the moisture content data from the bore log experiment. Then this result was compared with resistivity data to determine the relationship. This part was done using two methods which was lab test and field work. The author only focused on field work at site 1 behind Building 13.

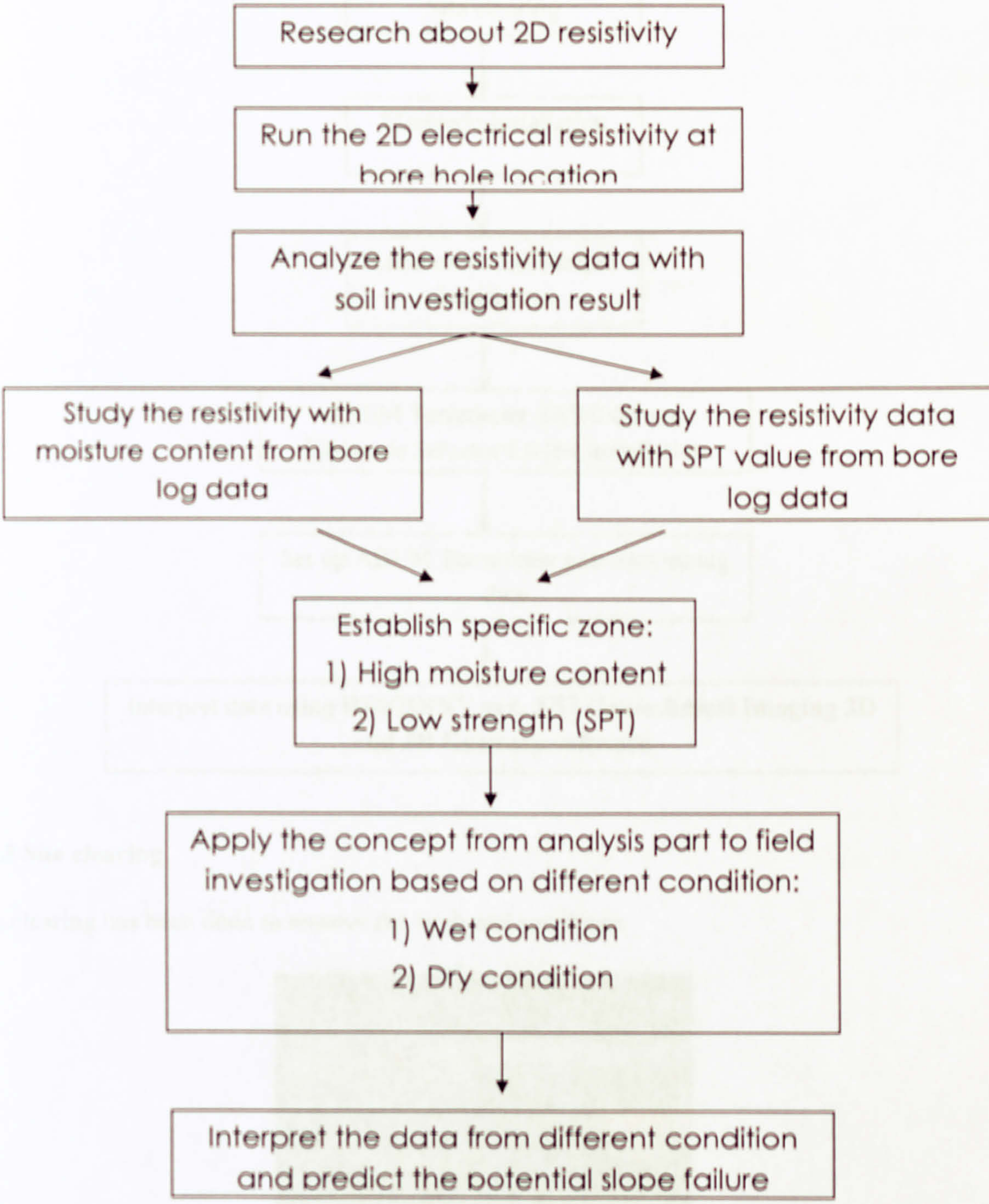
4.2 Study of relationship between SPT value and resistivity data.

This part focuses on the SPT value from the bore log data at site 1 which is located at the slope behind Building 13 in UTP. SPT values show the hardness of the soil and from that the author studies the relationship between the SPT value and electrical resistivity data.

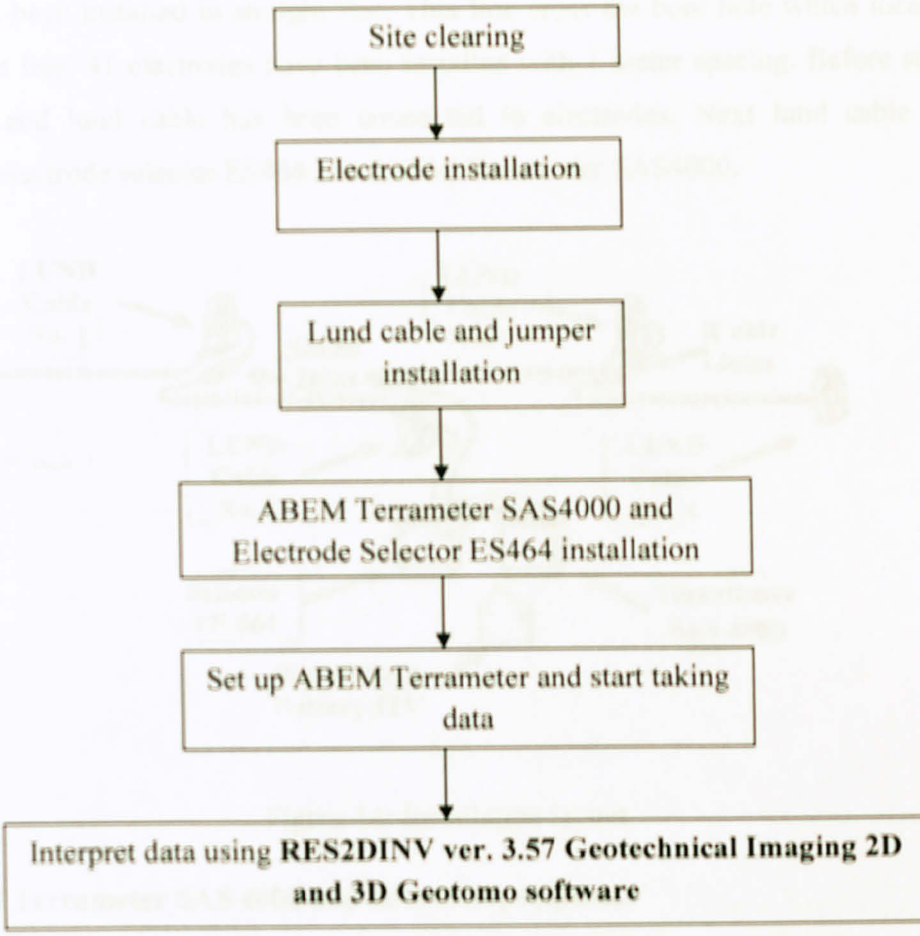
4.3 Field study

The author had run several lines of resistivity with different conditions at site 1. This is to study the effect of wet and dry conditions to the resistivity data. In this study the author used the Wenner array protocol. Before proceeding with the site investigation itself, steps were drawn out in aflow chart to clear out on the flow. Below are the steps and explanations on the site investigation using electrical resistivity.

4.3.1 Flow chart of Research



4.3.2 Site Investigation flow chart



4.3.3 Site clearing

Site clearing has been done to remove the bush and small tree.

Figure 13: Site

4.3.4 Electrode installation

Electrode has been installed in straight line. This line cross the bore hole which located in the middle of that line. 41 electrodes have been installed with 1 meter spacing. Before start taking data jumper and lund cable has been connected to electrodes. Next lund cable has been connected to electrode selector ES464 and ABEM Terrameter SAS4000.

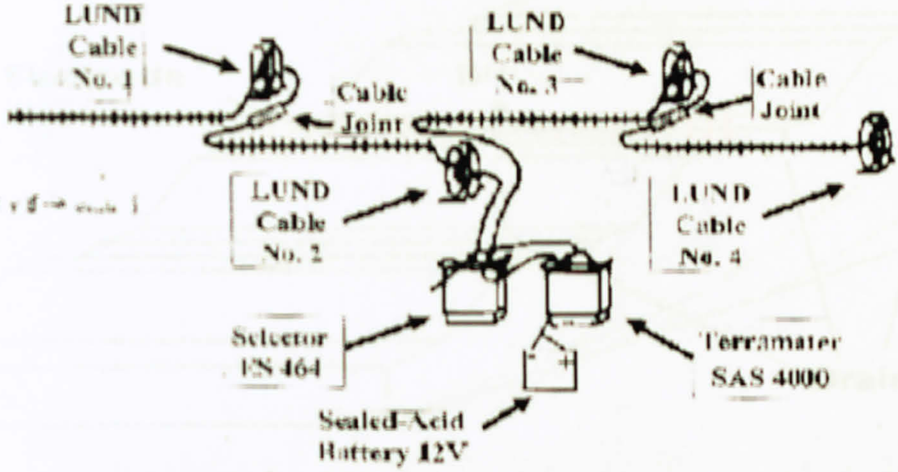


Figure 14: Installation layout

4.3.5 ABEM Terrameter SAS 4000 and data interpretation.

In this part the author has been used Wenner array protocol inside ABEM Terrameter SAS 4000. After finish taking data, author interprets data using RES2DINV ver. 3.57 Geotechnical Imaging 2D and 3D Geotomo software.

Figure 15: ABEM Terrameter SAS 4000 installation.

CHAPTER 5

5.0 RESULT AND DISCUSSION

5.1 Site 1

a) Relationship between moisture content with resistivity.

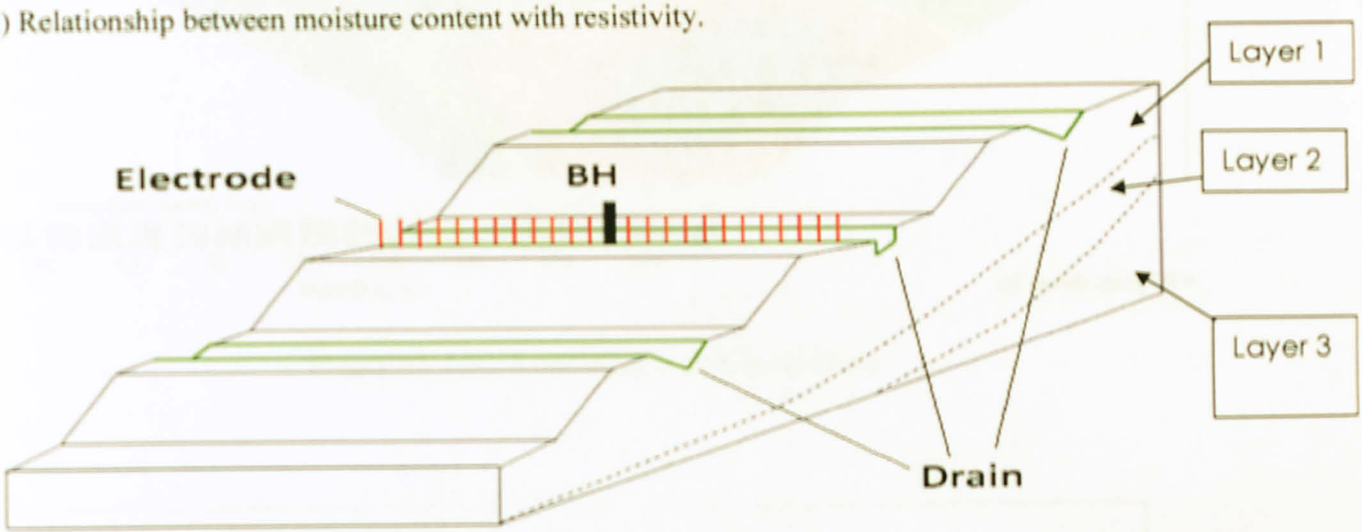


Figure 16: electrode installation for line 3 at site 1

Table 3: Data base on bore log and resistivity

	depth, m	moisture content %	resistivity value, k.ohm.m
	1.0	32	0.3
	2.0	29	0.8
	3.0	26	3.0
	4.0	24	5.0
	5.0	23	6.5
	6.0	22	7.6
Water level	**7.0**	**24**	
	8.0	22	
	9.0	20	
	10.0	17	
	11.0	17	
	12.0	16	
	13.0	13	
	14.0	13	
	15.0	12	
	16.0	15	
	17.0	13	
	18.0	11	

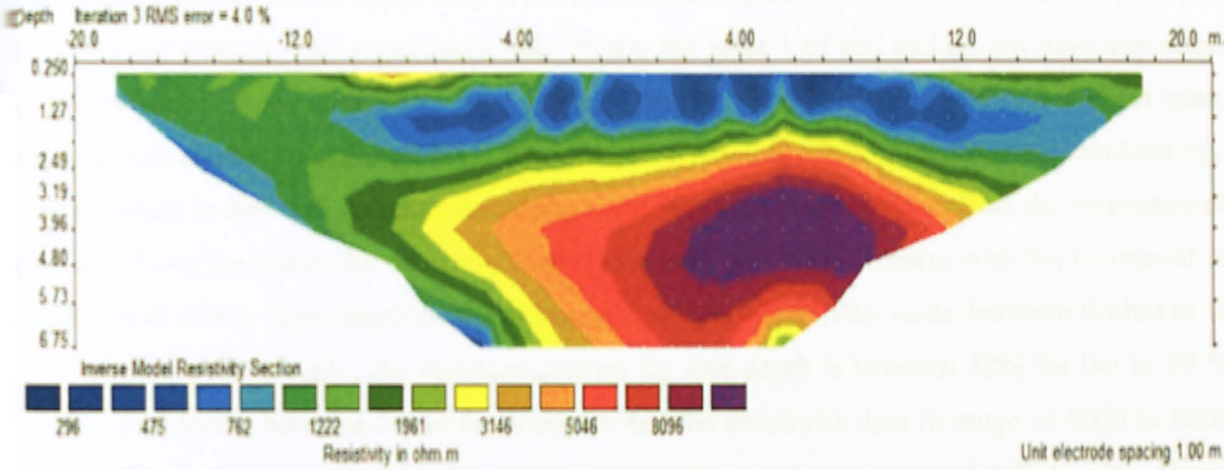


Figure 17: Line 3 electrical resistivity at site 1

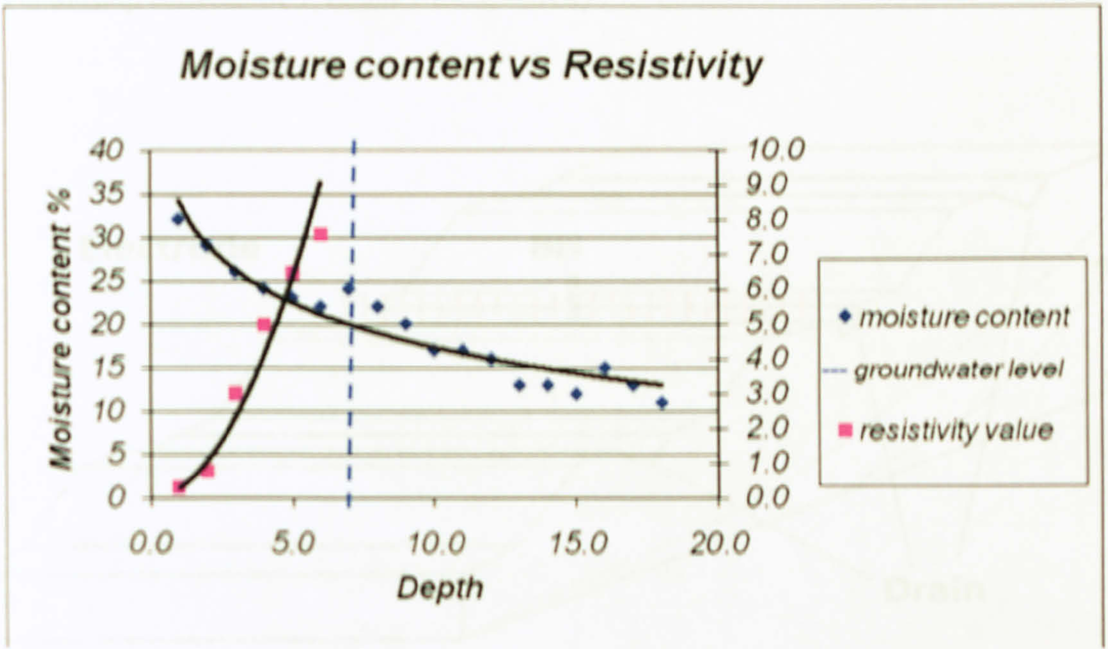


Figure 18: Moisture content versus resistivity

This part involves two types of field experiment which is bore log and electrical resistivity. The electrical resistivity test is depth only at about 6.75 m. this situation happened because the cable length is not enough. This experiment only effects the layer 1 of soil and do not have any effect of groundwater. Based on the data from graph, it shows that electrical resistivity decreases when the moisture content increases. This is because resistivity test is based on electrical conductivity. The moisture in soil will increase the conductivity between soil and this effect the resistance of that soil. Form the resistivity data, its shows that resistivity value increases with the increment of depth. Most of top layer depth between 0m to 2 m has a resisivity value between 0 ohm.m to 1000 ohm.m. Additionally, the moisture content for that depth is between 32% for 0m to 29 % for 2m. For depths between 5m to 6m it shows that the resistivity data in range of 6000 to 8000 ohm.m. The moisture content for this depth, on the other hand is in range of 23% to 22%. Based on this analysis, its shows that the increment of moisture content will decrease the resistivity value.

b) Relationship between SPT values with resistivity

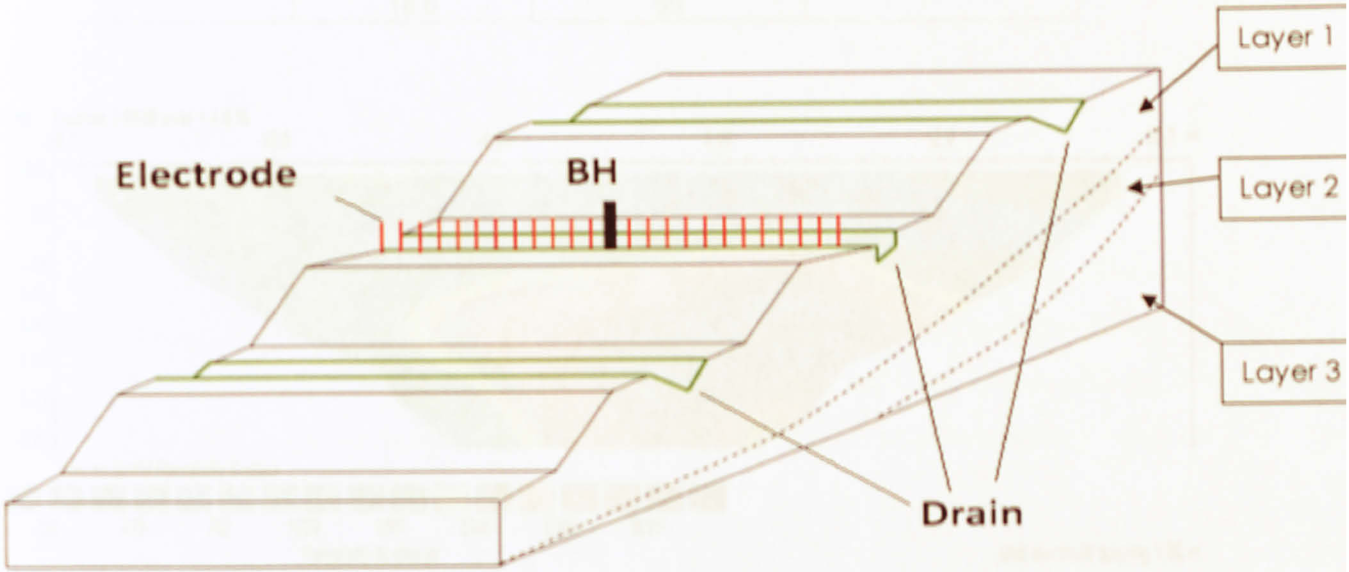


Figure 19: electrode installation for line 3 at site 1

Table 4: Data base on bore log and resistivity

	depth, m	SPT (N value)	resistivity value, k.ohm
	1.0		0.3
	2.0		0.8
	3.0	10	3.0
	4.0	9	5.0
	5.0		6.5
	6.0		7.6
Water level	**7.0**	**9**	
	8.0	9	
	9.0	9	
	10.0	25	
	11.0	25	
	12.0	50	
	13.0	50	
	14.0	50	
	15.0	50	
	16.0	50	
	17.0	50	
	18.0	50	

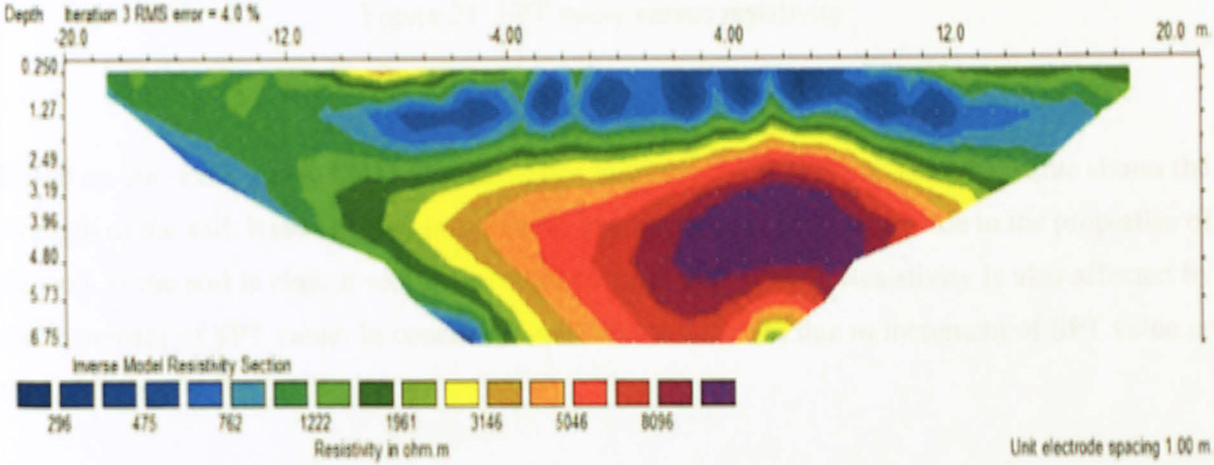


Figure 20: Line 3 electrical resistivity at site 1

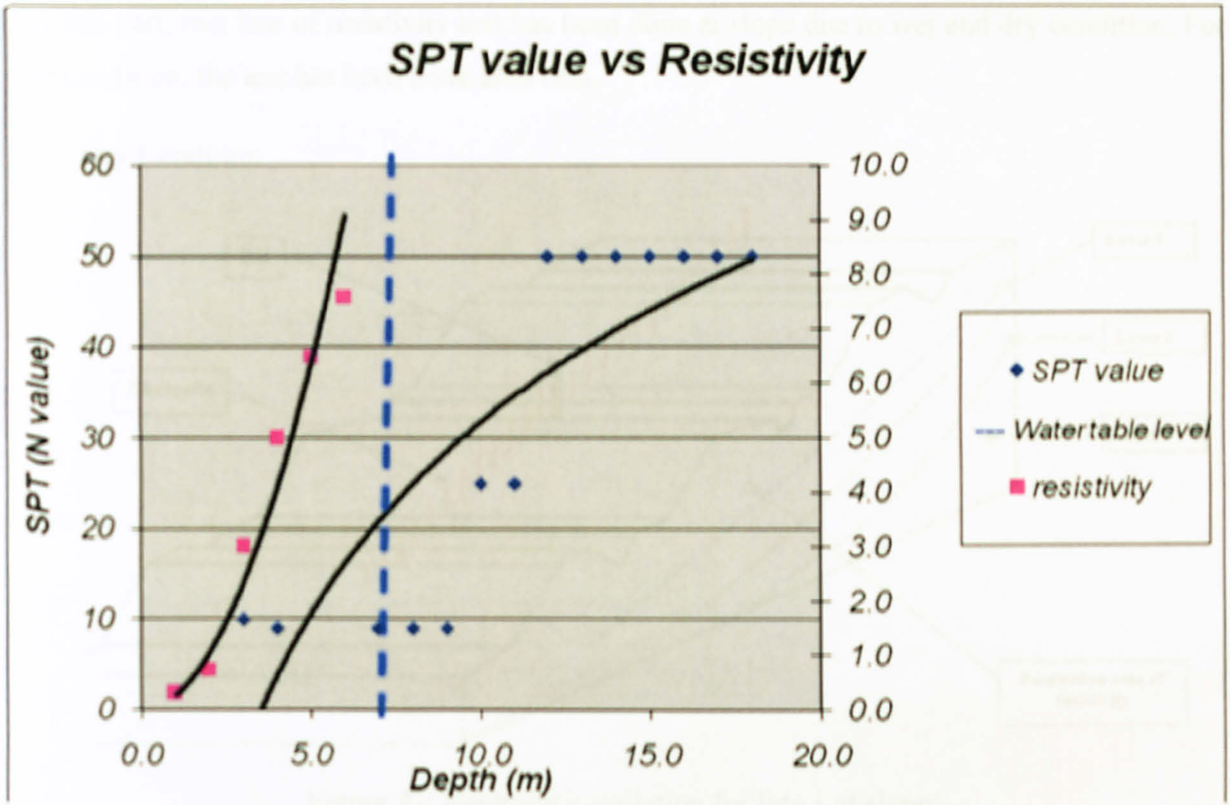


Figure 21: SPT value versus resistivity

Based on the result graph, SPT value increases until the N-value is 50. The SPT value shows the strength of the soil. Based on this information, the strength value changes due to the properties of the soil. If the soil is clay, it will have lower strength than gravel. Resistivity is also affected by the increment of SPT value. In conclusion, resistivity increases due to increment of SPT value or the strength of soil.

c) The effect of wet and dry condition to resistivity data.

For this part, two line of resistivity test has been done at slope due to wet and dry condition. For wet condition, the test has been done after rain.

i. Dry Condition

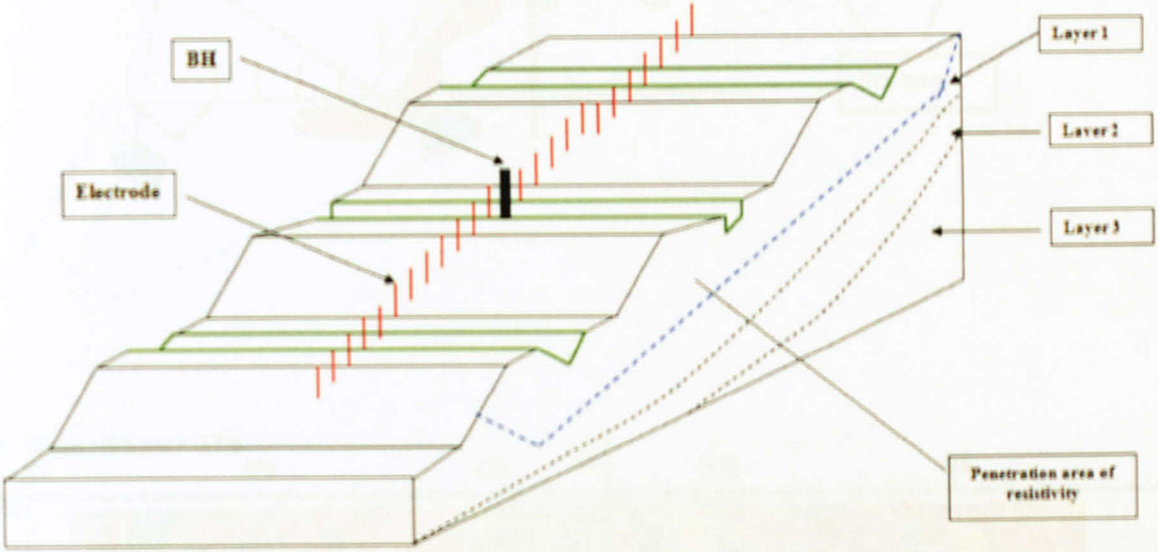


Figure 22: electrode installation for line 1 at slope

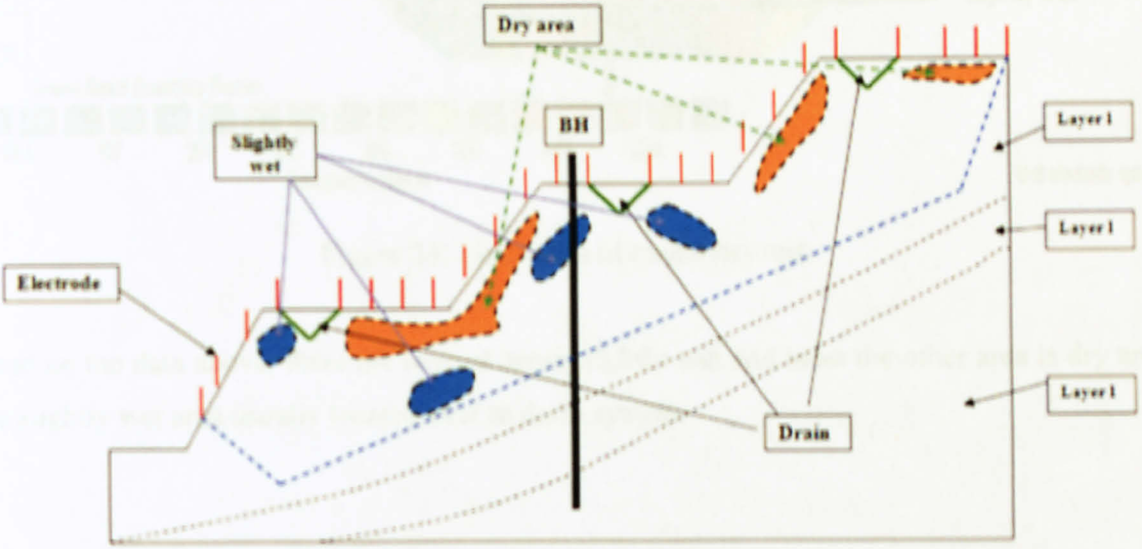
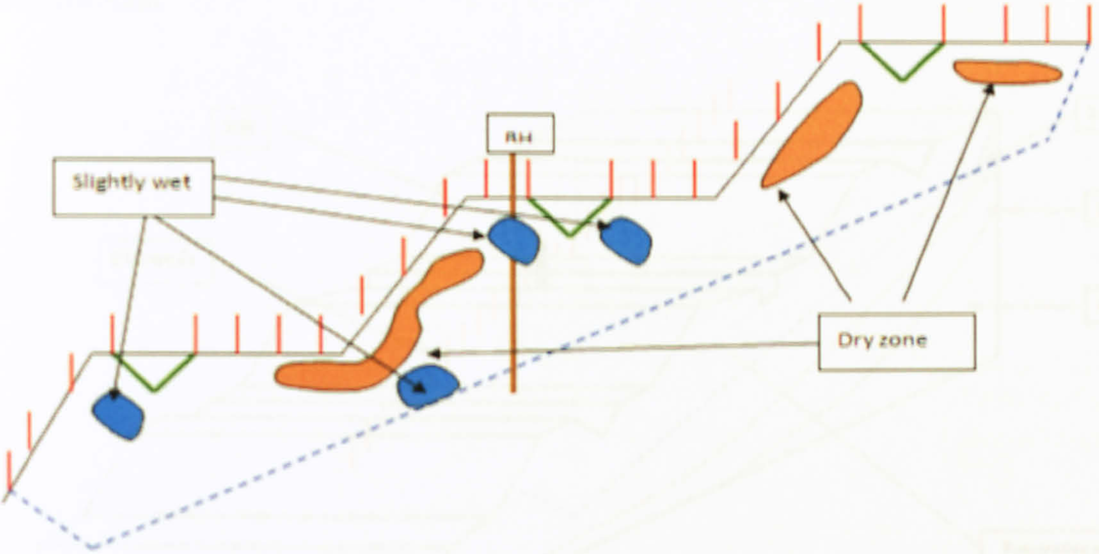


Figure 23: Cross section of dry condition area.



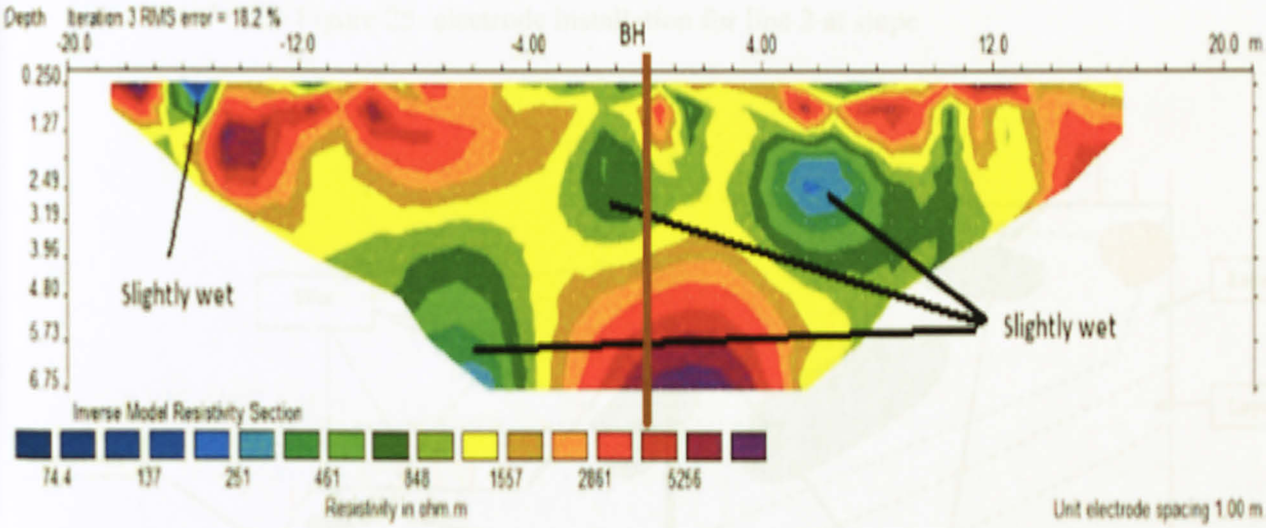


Figure 24: Line 1data of resistivity test.

Based on the data above, there are several areas slightly wet and most the other area is dry area. The slightly wet area usually located near to drain system.

Wet condition

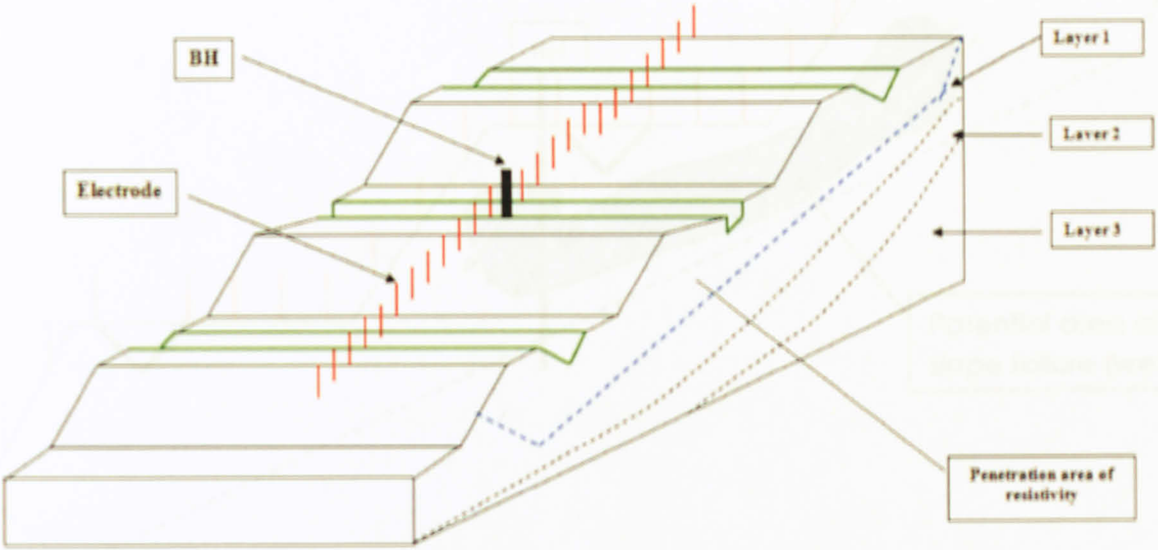


Figure 25: electrode installation for line 2 at slope

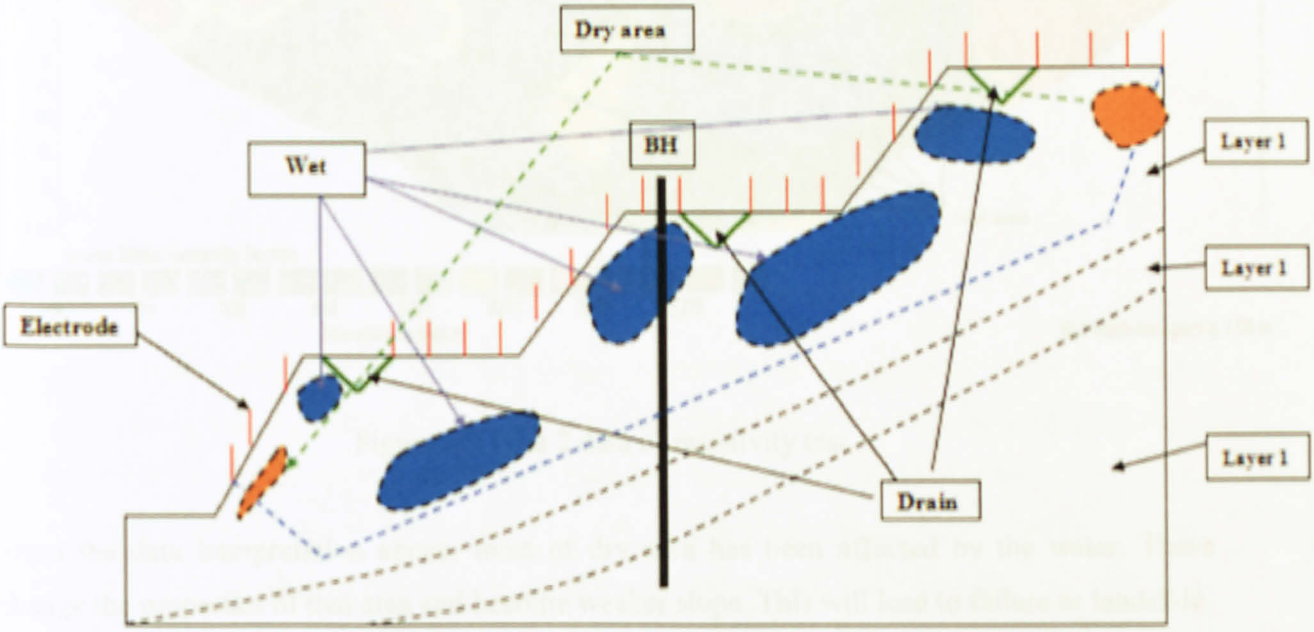


Figure 26: Cross section of wet condition area.

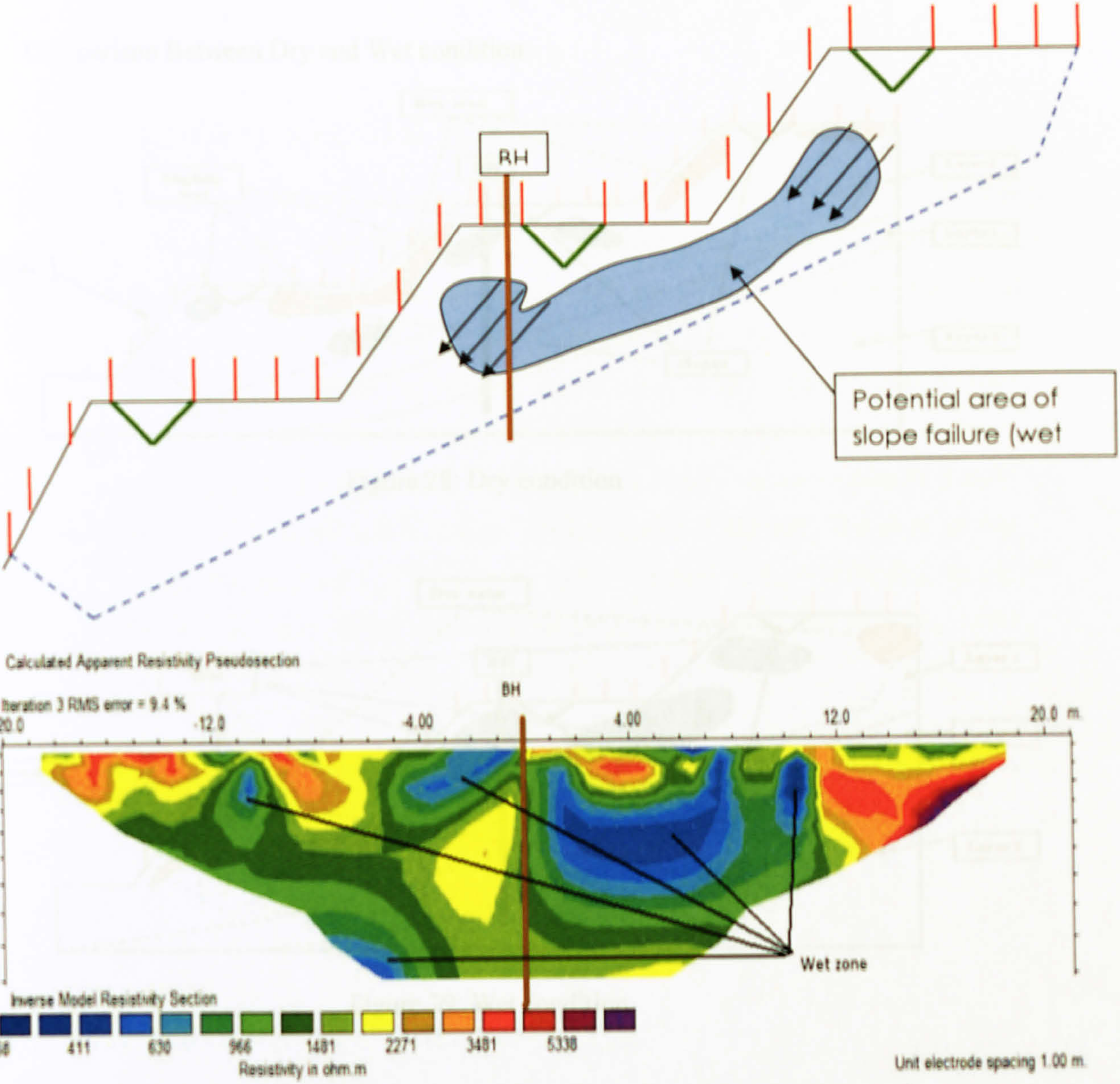


Figure 27: Line 2 data of resistivity test.

From the data interpretation above, most of dry area has been affected by the water. These change the properties of that area and become weaker slope. This will lead to failure or landslide.

iii. Comparison Between Dry and Wet condition

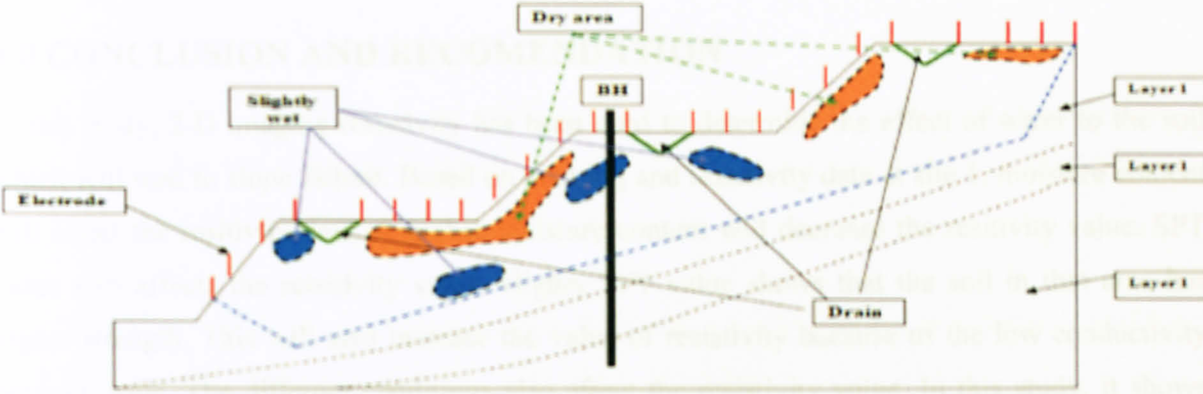


Figure 28: Dry condition

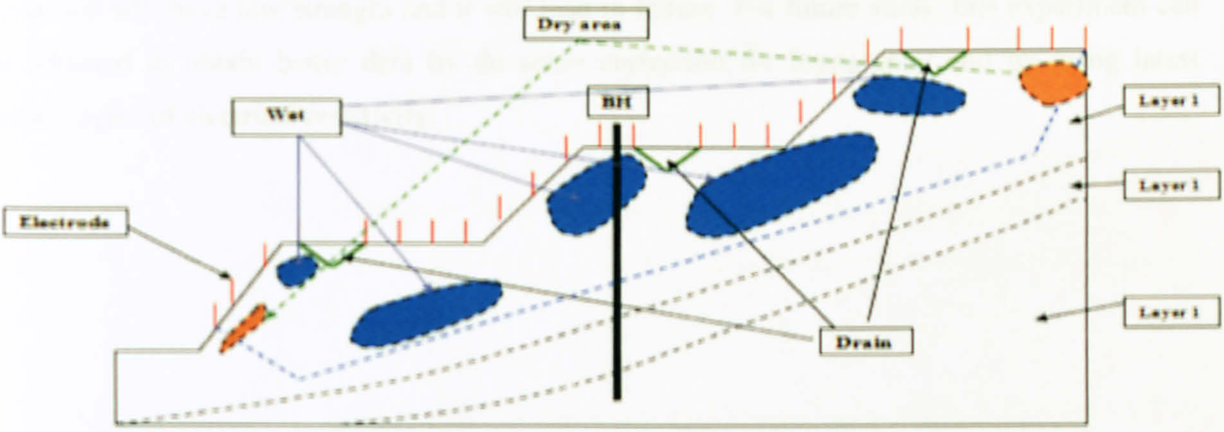


Figure 29: Wet condition

From both lines with different condition, these interpretations can be made. There is a higher potential of slope failure due to changing of condition from dry to wet. This water goes through the soil by the drainage system, which is imperfect. Unfortunately, both resistivity tests do not have accurate data. This is because some errors occur during the experiment. The penetrations of resistivity are also shallow because the cable is not long enough and the equipment is not up to date. The main error during this resistivity test is that the data taken are not corrected due to topography conditions.

CHAPTER 6

6.0 CONCLUSION AND RECOMENDATION

In this study, 2-D imaging resistivity has been used to determine the effect of water to the soil which will lead to slope failure. Based on bore log and resistivity data at site 1, moisture content will affect the resitivity data. A higher moisture content will decrease the resitivity value. SPT value also affects the reisitivity value. Higher SPT value shows that the soil in that area has higher strength. This will also increase the value of resistivity because of the low conductivity between soils. The different conditions also affect the resistivity value. In this study, it shows that wet conditions will decrease the resistivity value. This situation is because moisture content during wet conditions will increase and it changes the properties of the soil. The slope in wet condition will have low strength and it will lead to failure. For future study, this experiment can be adjusted to obtain better data by do some correction for topography and by using latest technologies of electrical resistivity.

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APPENDICES

APPENDIX A:

GANTT CHART

Gantt chart is use to show the schedule of this project from the scratches till the end process and final report is submitted. The following Gantt chart is the schedule of this project for the first and second semester.

Gantt chart for first semester

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	Mid Semester Break	11	12	13	14	15
1	Selection / Proposal of Project Topic																
2	Literature Review and Theory																
3	Submission of Journal and article				•												
5	Research methodology																
6	Essential Properties, Fundamental Theory of 2D electrical resistivity																
7	Submission of Progress Report						•										
8	Electrical resistivity test at site 2																
9	Electrical resistivity test at site 1																
10	Submission of Interim Report Final Draft													•			
11.	Oral presentation Submission Project																•

Gantt chart for Second semester

No	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	Project work continue for site 1																					
2	Submission of progress report (1 and 2)							•														
3	Interpretation of electrical resistivity data																					
5	Poster Exhibition										Mid Semester Break		•									
7	Submission of Dissertation (softbound)															•						
8	Preparation for oral presentation																					
9	Oral presentation																				•	
10	Submission of Project Dissertation (hardbound)																					•

APPENDIX B:

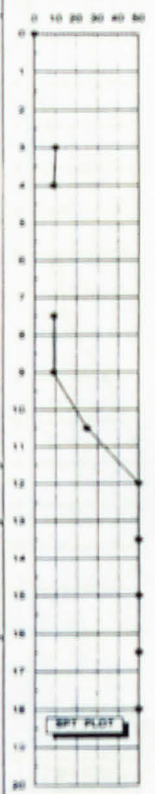
BORE HOLE LOG DATA AT SITE 1

ENGINEERING BOREHOLE LOG

Sheet 1of 2

Project	PROPOSED REMEDIAL WORKS FOR SLOPE FAILURE NEAR BLOCK 13, UNIVERSITI TEKNOLOGI PETRONAS, PERAK
Client	PMEM (UTP)
Consultant	CIVIL ENGINEERING DEPARTMENT
Rig Type	YWE
Drill Method	Rotary wash
Casing Type	NW
Driller	Kannan
Supervisor	Marotha Raju
Borehole No	BH - 1
Reduce Level	
Water Level	4.10m
Date Start	30.11.2008
Date Finish	01.12.2008

Depth m	Strata Thick ness	Description of Strata	Log	Sample No	Type	Depth, m From	Depth, m To	Rec Ratio	75	75	75	75	75	75	For P<75	N Value	For P<300
						0.00											
1		Stiff, yellow brown clay with sandy SILT		UD 1		1.00	2.00	50%									
3		Stiff, orange brown clay with sandy SILT		P1/D1		3.00	3.45	62%	1	2	2	2	3	3		10	
4.5	6.00	Stiff, reddish brown clay with sandy SILT with some gravels		P2/D2		4.50	4.95	67%	1	2	2	2	2	3		9	
6		Medium stiff, pinkish brown clayey SILT with some sand		UD 2		6.00	6.50	100%									
7.5	8.00	Stiff, light pinkish brown light grey clayey SILT with some sand		P3/D3		7.50	7.95	76%	2	1	2	2	2	3		9	
9		Stiff, light yellow pink clay with sandy SILT		P4/D4		9.00	9.45	67%	2	2	2	2	2	3		9	
10.5		Very stiff, light yellow brown clay with sandy SILT		P5/D5		10.50	10.95	62%	2	4	6	6	7	6		25	
12	13.50	Hard, orange brown clay sandy SILT		P6/D6		12.00	12.375	53%	4	5	10	17	19	-		50 /225mm	
13.5		Dense, light yellow brown silty SAND		P7/D7		13.50	13.880	47%	5	7	12	13	13	8 / 5		50 /230mm	
15		- Ditto -		P8/D8		15.00	15.235	44%	7	8	34	16 / 20	-	-		50 /85mm	
16.5	18.00	Dense, light yellow brown silty SAND		P9/D9		16.50	16.800	60%	5	10	15	35	-	-		50 /150mm	
18	19.20	Very dense, light yellow silty gravelly SAND		P10/D10		18.00	18.100	100%	33 / 33	30 / 63	-	-	-	-		50 /65mm	
19.2		Very weak, light grey to brown highly weathered SANDSTONE		C 1		19.20	21.00		C/R(U) = 1.00 C/RE = 0.80 RQD = NIL								



Legend:

W	Water
D	Disturbed Sample
P	Standard Penetration Test
UD	Undisturbed Sample
V	Vane Shear Test
C	Rock Coring
W	Water Sample
N	No. of Blows/300mm

NOTE: Rec = Recovery

Date / Time	BH - Depth (m)	Casing Depth, m	Water Table
30.11.08	18.000	16.50	1.50
01.12.08	18.000	16.50	7.40
01.12.08	24.00	22.50	4.10

Example:
(50) / 120 50 Blows / 120mm

Cohesive Soil (N)	0	2	4	8	15	30
	V.soft	Soft	M.stiff	Stiff	V.stiff	Hard
Non-cohesive Soil (N)	0	4	10	30	50	
	Very loose	Loose	Med dense	Dense	Very dense	

(493228-T)
RK GEOTECHNIQUE SDN BHD

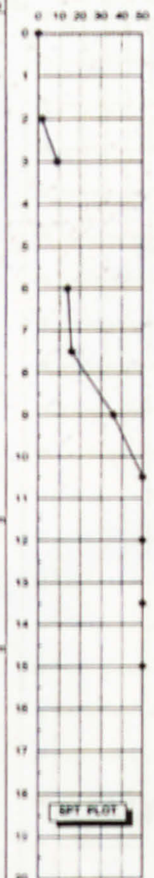
ENGINEERING BOREHOLE LOG

Sheet 1of 1.

Project	PROPOSED REMEDIAL WORKS FOR SLOPE FAILURE NEAR BLOCK 13, UNIVERSITI TEKNOLOGI PETRONAS, PERAK	Borehole No	BH - 2
		Reduce Level	
		Water Level	0.60m
Client	PMM (UTP)	Date Start	28.11.2008
Consultant	CIVIL ENGINEERING DEPARTMENT	Date Finish	29.11.2008

Rig Type	YWE	Driller	Kannan
Drill Method	Rotary wash	Supervisor	Marotha Raju
Casing Type	NW		

Depth m	Strata Thickness	Description of Strata	Log	Sample No		Depth, m From	Depth, m To	Rec Ratio	75	75	75	75	75	75	For P<75	N Value	For P>300
			++++			0.00											
1			++														
		Very soft, yellow clay with sandy SILT.	++++	UD 1	x	1.00	2.00	100%									
2		Soft, yellow brown clay with sandy SILT.	++	F1/D1	I	2.00	2.45	22%	0	0	0	0	1	1		2	
			++++														
3		Stiff, yellow brown sandy SILT with some gravels.	++	F2/D2	I	3.00	3.45	44%	1	2	2	2	2	3		9	
			++++														
4			++														
		Stiff, yellow brown clay with sandy SILT with some little gravels.	++++	UD 2	x	4.50	4.70	100%									
5			++														
			++++														
6		Stiff, yellow to traces of brown clay with sandy SILT.	++	F3/D3	I	6.00	6.45	67%	2	2	3	3	4	4		14	
			++++														
7			++														
		Very stiff, yellow brown clay with sandy SILT.	++++	F4/D4	I	7.50	7.95	60%	2	3	4	4	4	4		16	
8			++														
			++++														
9		Hard, yellow brown sandy SILT with some gravels.	++	F5/D5	I	9.00	9.45	89%	3	3	4	7	12	13		36	
			++++														
10			++														
		Hard, yellow brown sandy SILT.	++++	F6/D6	I	10.50	10.95	78%	2	2	4	7	13	24		50	
11			++														
			++++														
12		Hard, yellow brown traces sandy SILT with some gravels.	++	F7/D7	I	12.00	12.370	81%	1	10	12	14	24/70	-		50 /220mm	
			++++														
13	13.50		++														
		Very dense, dark brown to pink silty gravelly SAND.	+	F8/D8	I	13.50	13.695	100%	5	12	50/45	-	-	-		50 /45mm	
14			+														
	15.00		+														
15		Hard, dark brown gravelly SILT.	++++	F9/D9	I	15.00	15.375	73%	5	10	12	13	25	-		50 /225mm	
			++++														
16		END OF BH - 2 AT DEPTH 15.375m															
17		Installed Standpipe at depth 6.00m															
18																	
19																	
20																	



RK GEOTECHNIQUE SDN BHD

Legend

M		Mazier
D		Disturbed Sample
F	I	Standard Penetration Test
UD	x	Undisturbed Sample
V		Vane Shear Test
C		Rock Coring
W		Water Sample
N		No. of Blows/300mm

NOTE: Rec = Recovery

Date / Time	BH - Depth (m)	Casing Depth, m	Water Table
28.11.08	15.375	15.00	4.50
29.11.08	15.375	15.00	0.60

Example: (50) / 120 50 Blows / 120mm

Cohesive Soil (N)	0	2	4	8	15	30
	V.soft	Soft	M.stiff	Stiff	V.stiff	Hard
Non-cohesive Soil (N)	0	4	10	30	50	
	Very loose	Loose	Med dense	Dense	Very dense	

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RK GEOTECHNIQUE SDN BHD

ENGINEERING BOREHOLE LOG

Sheet 2 of 2

Project :	PROPOSED REMEDIAL WORKS FOR SLOPE FAILURE NEAR BLOCK 13, UNIVERSITI TEKNOLOGI PETRONAS, PERAK				Borehole No : BH - 1 Reduce Level : Water Level : 4.10m
Client :	PMM (UTP)	Rig Type : YWE		Driller : Kannan	Date Start : 30.11.2008
Main Contractor :	CIVIL ENGINEERING DEPARTMENT	Drill Method : Rotary wash		Supervisor : Moratha Raju	Date Finish : 01.12.2008
		Casing Type : NW			

Depth m	Strata Thickness	Description of Strata	Log	Sample No	From (m)	To (m)	Rec Ratio	SPT BLOW COUNT (Penetration, P (mm) 75/75/75/75/75/75)	For P<75	N Value	For P<300
21	21.00	Very weak light brown highly weathered SAND STONE		C 2	21.00	22.50		C/RUN = 1.50 C/RE = 0.60 RQD = NIL			
22–24		Very weak light pinkish brown highly weathered SAND STONE		C 3	22.50	24.00		C/RUN = 1.50 C/RE = 0.50 RQD = NIL			
		END OF BH - 1 AT DEPTH 24.00m Installed Standpipe at depth 19.50m									

Depth scale: 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40

SPT PLOT: 0 10 20 30 40 50 (depth 20 – 40)

RK GEOTECHNIQUE SDN BHD

Legend:

- M — Mazier
- D — Disturbed Sample
- P — Standard Penetration Test
- UD — Undisturbed Sample
- V — Vane Shear Test
- C — Rock Coring
- W — Water Sample
- N : No. of Blows/300mm

NOTE: Rec = Recovery

Date / Time	BH : Depth (m)	Casing Depth, m	Water Table
30.11.08	16.800	16.50	1.50
01.12.08	16.800	16.50	7.40
01.12.08	24.00	22.50	4.10

Example:
(50) / 120 50 Blows / 120mm

Cohesive Soil (N): 0, 2, 4, 8, 15, 30 — V.Soft, Soft, M.Stiff, Stiff, V.Stiff, Hard

Non cohesive Soil (N): 0, 4, 10, 30, 50 — Very loose, Loose, Med Dense, Dense, Very Dense

(493228-T)
RK GEOTECHNIQUE SDN BHD

APPENDIX C:

BORE HOLE SUMMARY AT SITE 1

GSE B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)
No. 30G, Jalan PS 5, Taman Prima Selayang, Off Jalan Rawang, 68100 Selangor. Tel : 03 - 61373981 Fax : 03 - 61376139

SUMMARY OF LABORATORY TEST RESULTS

PROJECT: UNIVERSITI TEKNOLOGI PETRONAS.

BOREHOLE NO.	SAMPLE NO.	DEPTH (m)		NATURAL MOISTURE CONTENT, %	BULK DENSITY, Mg/m^3	DRY DENSITY, Mg/m^3	SPECIFIC GRAVITY	ATTERBERG LIMITS			TRIAXIAL COMPRESSION TEST (UU) - 38 mm		CONSOLIDATION TEST			SHEAR BOX TEST (60 x 60 mm)		CHEMICAL TEST				PARTICLE SIZE DISTRIBUTION, %			
		FROM	TO					LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %	APPARENT COHESION, kPa	ANGLE OF SHEARING RESISTANCE, ϕ	VOID RATIO, e	PRE. COMPRESSION LOAD, kPa	COMPRESSION INDEX, Cc	COHESION, kPa	ANGLE OF SHEARING RESISTANCE, ϕ	pH VALUE	SULPHATE CONTENT, %	ORGANIC CONTENT, %	CHLORIDE CONTENT, %	GRAVEL, > 2 mm	SAND, 0.06 - 2 mm	SILT, < 0.06 mm	CLAY
BH 1	UD 1	1.50	2.00	32	1.823	1.381	2.54	45	28	17	62	3	0.824	106	0.228			6.4	<0.01	0.05		0	14	51	35
	P 1 / D 1	3.00	3.45	26			2.68	40	27	13												3	58	25	14
	P 2 / D 2	4.50	4.95	24	1.980	1.597	2.64	41	29	12						0	32	6.6	<0.01	0.02		6	42	36	16
	UD 2	6.00	6.50	22	1.980	1.623	2.65	41	29	12	69	7	0.639	138	0.168							0	49	38	13
	P 3 / D 3	7.50	7.95	24			2.61	48	29	19								6.5	<0.01	0.02		1	35	38	26
	P 4 / D 4	9.00	9.45	20			2.61	40	27	13												0	36	42	22
	P 5 / D 5	10.50	10.95	17	2.122	1.814	2.66	44	27	17						0	35	6.7	<0.01	0.02		0	54	25	21
	P 6 / D 6	12.00	12.375	16			2.66	30	25	5												0	54	33	13

N P = Non Plasticity I S = Insufficient Of Sample

B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)

GSE B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)
No. 30G, Jalan PS 5, Taman Prima Selayang, Off Jalan Rawang, 68100 Selangor. Tel : 03 - 61373961 Fax : 03 - 61376139

SUMMARY OF LABORATORY TEST RESULTS

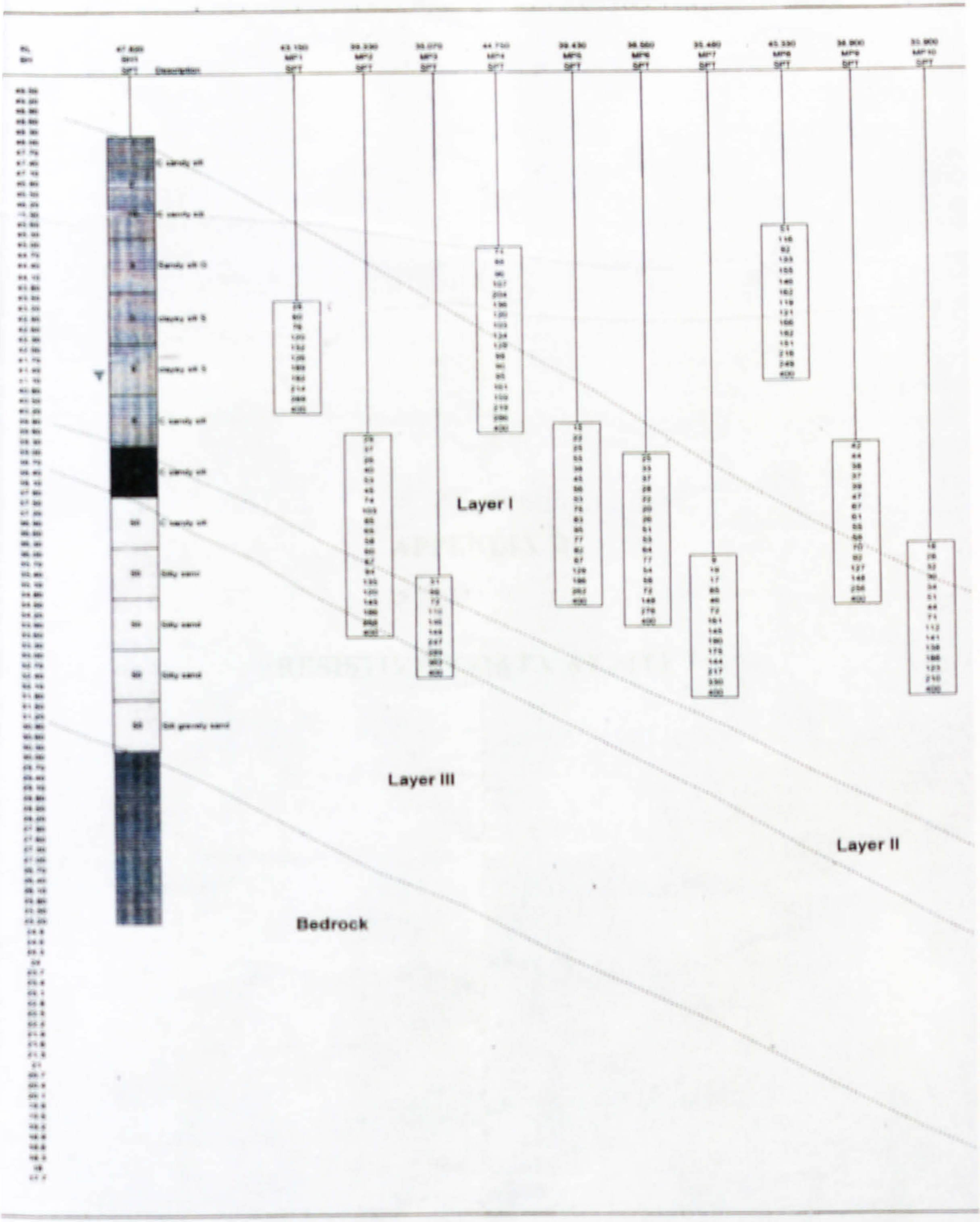
PROJECT: UNIVERSITI TEKNOLOGI PETRONAS.

BOREHOLE NO.	SAMPLE NO.	DEPTH (m)		NATURAL MOISTURE CONTENT, %	BULK DENSITY, Mg/m^3	DRY DENSITY, Mg/m^3	SPECIFIC GRAVITY	ATTERBERG LIMITS			TRIAXIAL COMPRESSION TEST (UU) - 38 mm		CONSOLIDATION TEST			SHEAR BOX TEST (60 x 60 mm)		CHEMICAL TEST				PARTICLE SIZE DISTRIBUTION, %			
		FROM	TO					LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %	APPARENT COHESION, kPa	ANGLE OF SHEARING RESISTANCE, ϕ	VOID RATIO, e	PRE. COMPRESSION LOAD, kPa	COMPRESSION INDEX, Cc	COHESION, kPa	ANGLE OF SHEARING RESISTANCE, ϕ	pH VALUE	SULPHATE CONTENT, %	ORGANIC CONTENT, %	CHLORIDE CONTENT, %	GRAVEL, > 2 mm	SAND, 0.06 - 2 mm	SILT, < 0.06 mm	CLAY
BH 1	P 7 / D 7	13.50	13.880	13			2.72	NP	NP	NP								6.8	<0.01	0.02		0	72		28
	P 8 / D 8	15.00	15.225	12			2.69	29	25	4												0	62	27	11
	P 9 / D 9	16.50	16.800	15	2.166	1.883	2.70	43	28	15						0	37	6.7	<0.01	0.02		0	67	20	13
	P 10 / D 10	18.00	18.100	11			2.69	35	27	8												1	61	27	11

N.P = Non Plasticity

I.S = Insufficient Of Sample

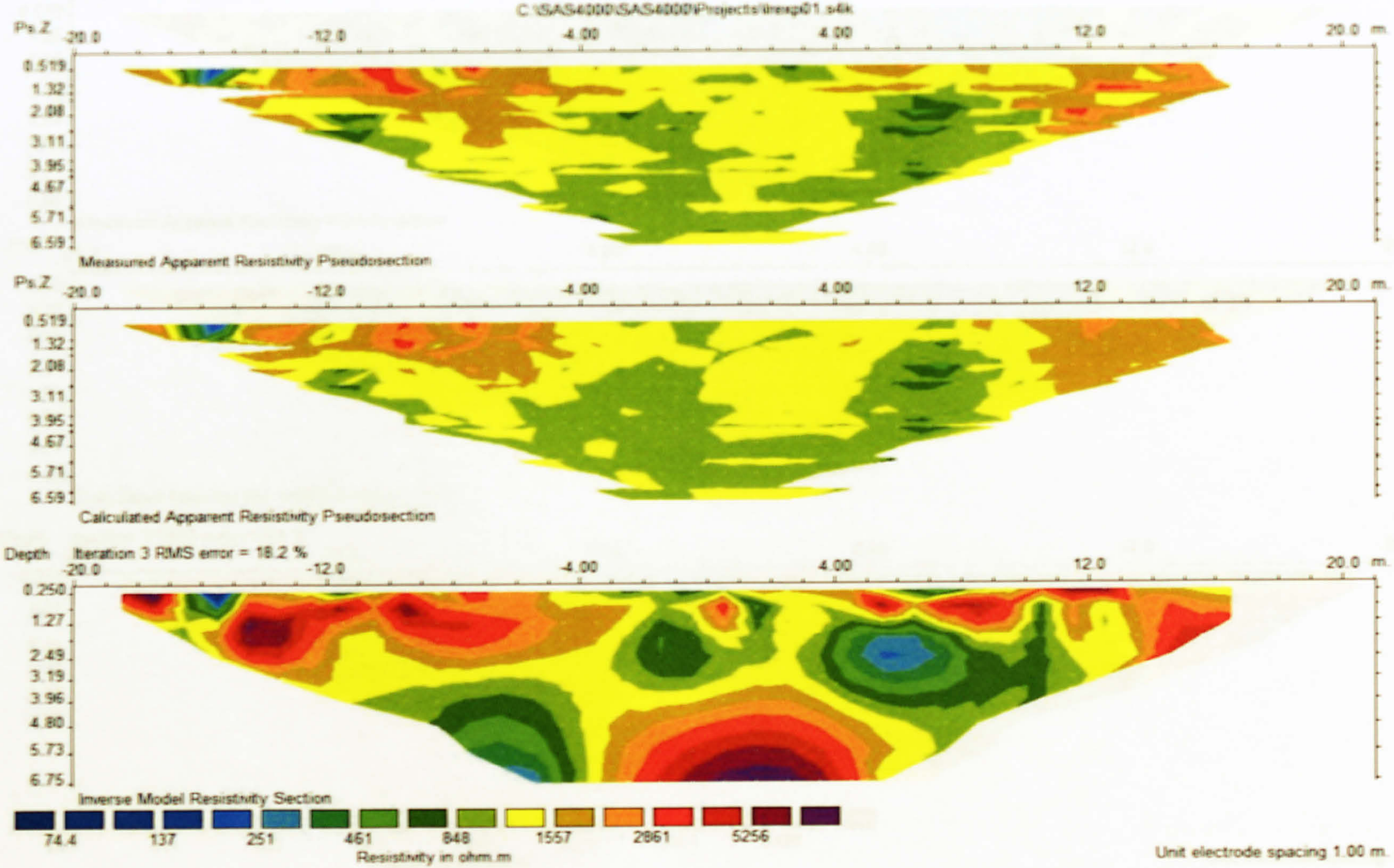
B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)


Layer I
Layer III
Layer II
Bedrock

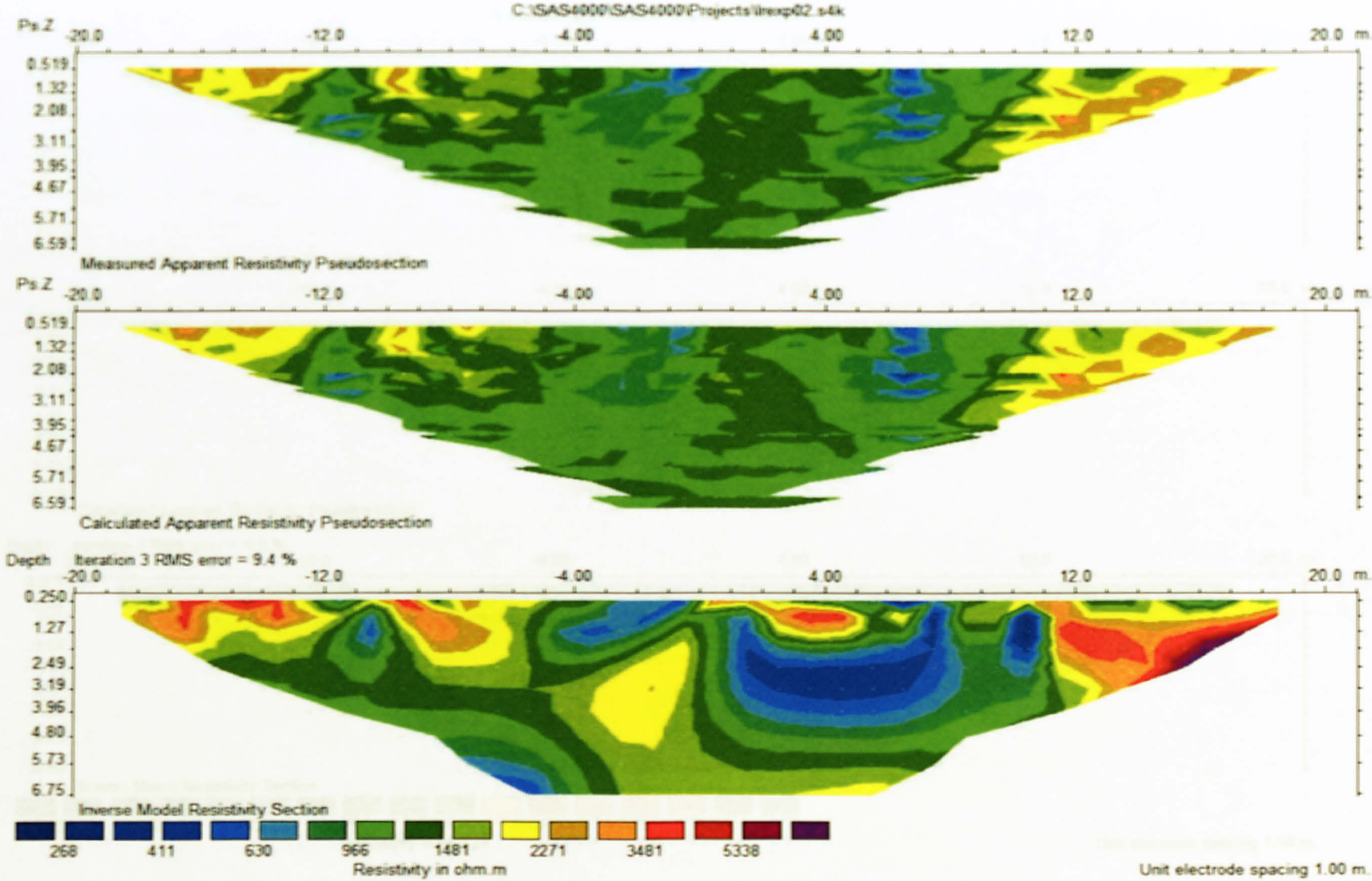
APPENDIX D:

RESISTIVITY DATA AT SITE 1

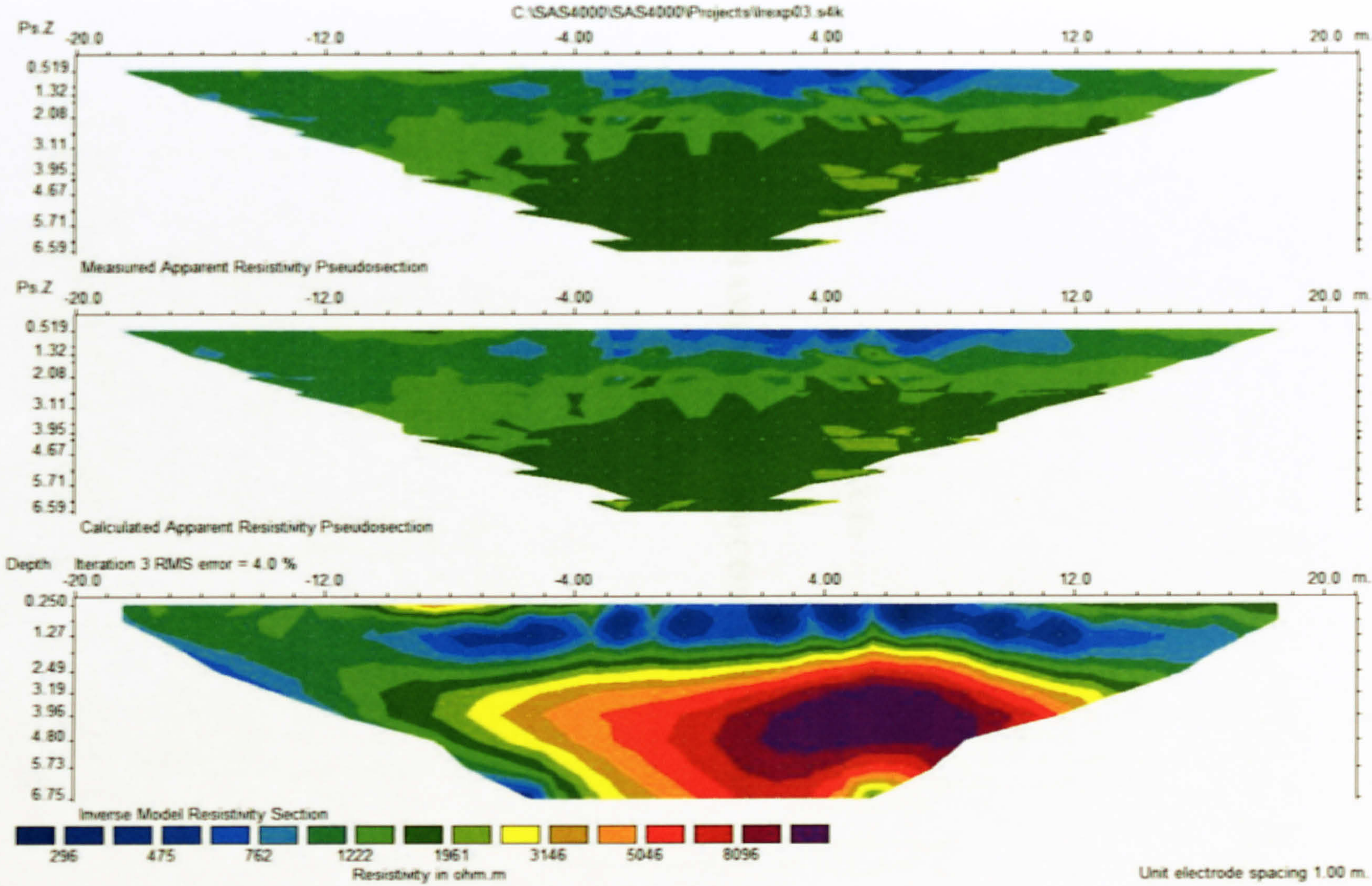
Resistivity data line 1



Resistivity data line 2



Resistivity data line 3



APPENDIX E:

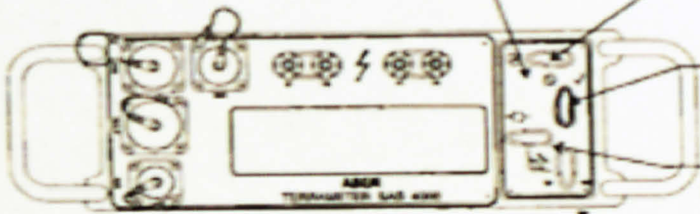
ABEM TERRAMETER SAS 4000 CONTROL KNOBS

SAS 4000

Control Knobs

POWER: press these two control knobs towards each other to turn on and turn off the instrument.

The MEASURE knob. Turn the knob upward or downward to perform a measurement.



✓ and ⊘ control knob. Turn the knob to the right to accept a menu choice, or to the left to cancel.

+( )- control knob. Used to increase/decrease values in data entry fields. Also used to scroll between menus.

⬅ / ➡ control knob. Used to move between fields.

Connector

PARALLEL connector. For communication with e.g. a printer.

SERIAL connector. For communication with external computers and other devices.

MULTI connector. For communication with e.g. the LUND cable system. Contains the potential connectors (P_1P_2) for all four channels plus the current terminals C_1C_2.

AUX connector. For communication with e.g. the SAS LOG 200 / 300

APPENDIX F:

PICTURES

Electrode setup for line 3

Bore hole at site 1

Electrode setup for line 1 and line 2